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(NASA-CR-172948) SPACE STATION NEEDS,  
ATTRIBUTES AND ARCHITECTURAL OPTIONS STUDY  
COMMERCIALIZATION WORKING GROUP BRIEFING  
Final Report (TRW Space Technology Labs.)  
155 p HC A08/MF A01  
CSC 42B G3/18 15001  
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APR 1983

Space Station Needs, Attributes  
and Architectural Options Study  
Commercialization Working  
Group Briefing  
NASW-3681 April 7, 1983

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**Space Station Needs, Attributes  
and Architectural Options Study  
Commercialization Working  
Group Briefing**

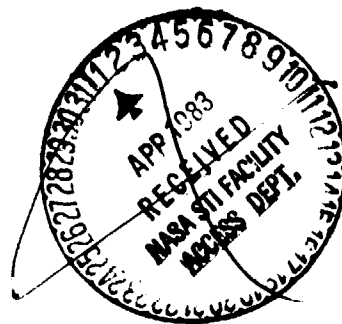
**NASW-3681 April 7, 1983**

## COMMERCIALIZATION MEETING AGENDA

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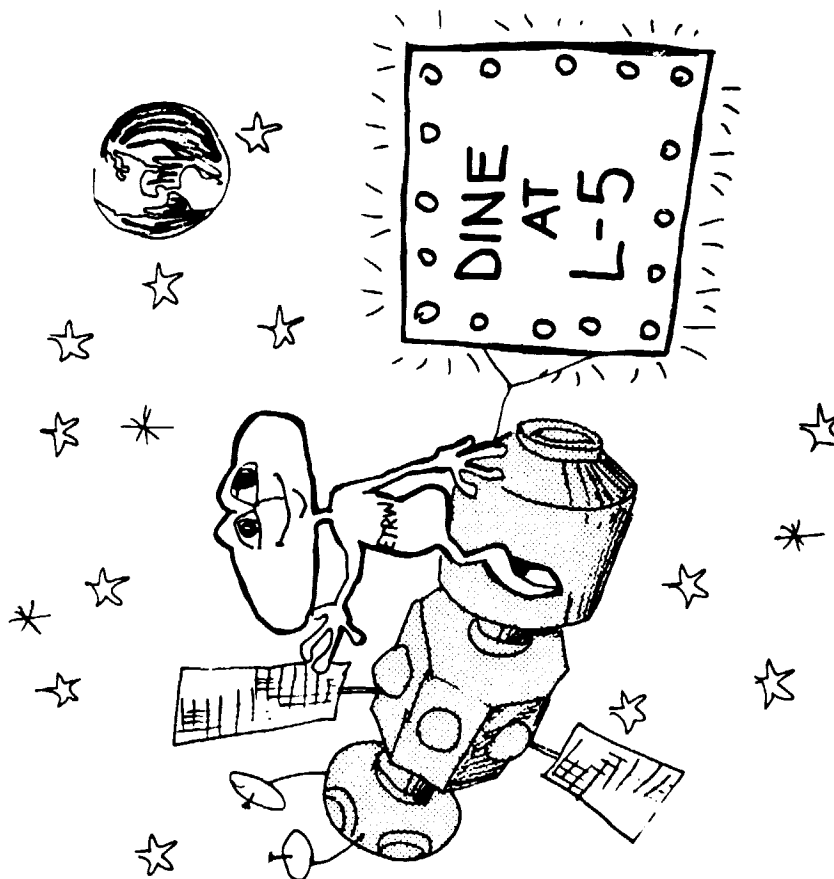
- SPACE STATION COMMERCIAL BENEFITS SUMMARY
- COMMERCIAL COMMUNICATIONS
- COMMERCIAL REMOTE SENSING
- COMMERCIAL MATERIALS PROCESSING IN SPACE
- LEO SATELLITE ASSEMBLY, TEST AND SERVICING
- SPACE TOURISM

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COMMERCIALIZATION

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## SPACE STATION COMMERCIAL BENEFITS SUMMARY

The facing page summarizes the foreseen benefits for each of the commercial areas investigated. These benefits are described in subsequent pages of this volume. In each case, where economic benefits are derived, the costs for accomplishing tasks with the Space Station are compared with the cost with the STS only (Scenario 0).



## SPACE STATION COMMERCIAL BENEFITS SUMMARY

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### COMMUNICATIONS (28.5° STATION)

- LARGE SYSTEM TESTING AND ASSEMBLY
- MULTIPLE SATELLITE TRANSSHIPMENT TO GEO
- AROTV\* LEO TO GEO LAUNCHES
- AROTV AIDED GEO SATELLITE SERVICING
- HIGHER STS LOAD FACTORS

### REMOTE SENSING (POLAR STATION)

- INSTRUMENT MAINTENANCE
- HIGHER STS LOAD FACTORS

### MATERIALS PROCESSING IN SPACE (28.5° STATION)

- LONG DURATION RESEARCH ENABLES EARLIER PRODUCTION
- AVOIDS NEED TO RE-LAUNCH SPACELAB FACILITY
- HIGHER STS LOAD FACTORS

### LEO SATELLITE ASSEMBLY, TEST AND SERVICING – LOWER COST, EXTENDED LIFE

### SPACE TOURISM – TRAVEL TO A SPACE STATION

\*AROTV = AEROBRAKED RETURNABLE OTV

## SPACE STATION ARCHITECTURE SCENARIOS

Six different candidate scenarios were examined. All had free-flying spacecraft, small unmanned platforms, TMS and OTV's in common.

Scenario 0 is the baseline. This assumes neither SS or SP. It is what would/could be done without those elements. Scenario 1 adds Space Platforms. Scenario 2 has Space Stations, but no Space Platforms. Scenario 3 has an SS at LEO and one or more SP's at PE0.

Scenario 4 has SS's at LEO and PE0 and an SP at LEO. Scenario 5 is like Scenario 4, except that an extended-stay Orbiter is used as part of the initial SS.

## Space Station Architecture Scenarios



SCENARIO	SPACE PLATFORM		SPACE STATION	
	LEO*	PEO	LEO	PEO
0				
1	X	X		
2			X	X
3		X	X	
4	X		X	X
5**	X		X	X

\*LEO - LOW INCLINATION (28.5°) LOW EARTH ORBIT

PEO - POLAR (97°) LOW EARTH ORBIT

\*\*USES STS AS PART OF INITIAL SS

ALL SCENARIOS INCLUDE FREE FLIERS, SMALL UNMANNED PLATFORMS, TMS, OTV'S



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# Commercial Communications

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TRW Supported by Communications 21 Corporation

## COMMUNICATIONS QUESTIONNAIRE RESPONDENTS

Ninety-one senior professionals in the field of commercial communications were sent a carefully prepared questionnaire by our subcontractor, Communications 21 Corp. Of these, 23 responses were received, some from multiple addressees in a single company. All who responded were asked to attend a meeting to discuss the results of the survey and to comment further on possible Space Station missions regarding commercial communications. Two meetings were held, one in New York and one in Los Angeles. Both were well attended and resulted in interested and responsive discussions.

The respondent companies are listed on the facing page.



## COMMUNICATIONS QUESTIONNAIRE RESPONDENTS\*

<u>COMPANY</u>	<u>RELATIONSHIP TO SPACE COMMUNICATIONS</u>
COMSAT GENERAL CORP	CARRIER
ITT COMMUNICATIONS OPERATIONS GROUP	CARRIER
WESTERN UNION TELEGRAPH CO	CARRIER
GTE SATELLITE CORP (2)	CARRIER
SATELLITE BUSINESS SYSTEMS (3)	CARRIER
NATIONAL PUBLIC RADIO	CARRIER
RCA AMERICOM	CARRIER
HAWAIIAN TELEPHONE CO	CARRIER
APPALACHIA REGIONAL COMMISSION	EDUCATIONAL CARRIER
FEDERAL COMMUNICATIONS COMMISSION (2)	REGULATORY
MIT LINCOLN LABORATORY	COMM RESEARCH
BELL LABORATORIES	RESEARCH
JET PROPULSION LABORATORY	RESEARCH
DIGITAL COMMUNICATIONS CORP	RESEARCH
THE MITRE CORP	COMMUNICATIONS STUDIES
SPACETECH, INC.	CONSULTANT
MILLENNIUM III CORP	CONSULTANT
AEROJET LIQUID ROCKET CO.	CONSULTANT
TRW	SPACECRAFT MFG.

\*RESPONDENTS NUMBERED 23 OUT OF 91

COMMERCIAL COMMUNICATIONS  
SURVEY MEETING RESULTS

Senior professionals in the field of commercial communications were sent questionnaires and a number were interviewed in face to face meetings. Analysis of these data source established the facing page strong majority statements. Each is elaborated in following charts.



- THERE ARE REQUIREMENTS FOR LEO TESTING OF EQUIPMENT SUCH AS LARGE ANTENNAS
- ASSEMBLY OF SPACECRAFT IN LEO, FOR BOOST TO GEO, WAS ACCEPTED AS A COST SAVING CONCEPT
- THE UPDATED TRAFFIC MODEL, BASED ON USER INPUTS, PREDICTS A NEED FOR 10 TO 20 NEW SATELLITES PER YEAR FOR THE NEXT 20 YEARS
- GROWTH IN DEMAND FOR VIDEO CHANNELS WAS CITED AS THE SINGLE MOST IMPORTANT FACTOR OF THE FORECASTED INCREASE IN SATELLITE TRAFFIC (LATE 1980's AND 1990's)

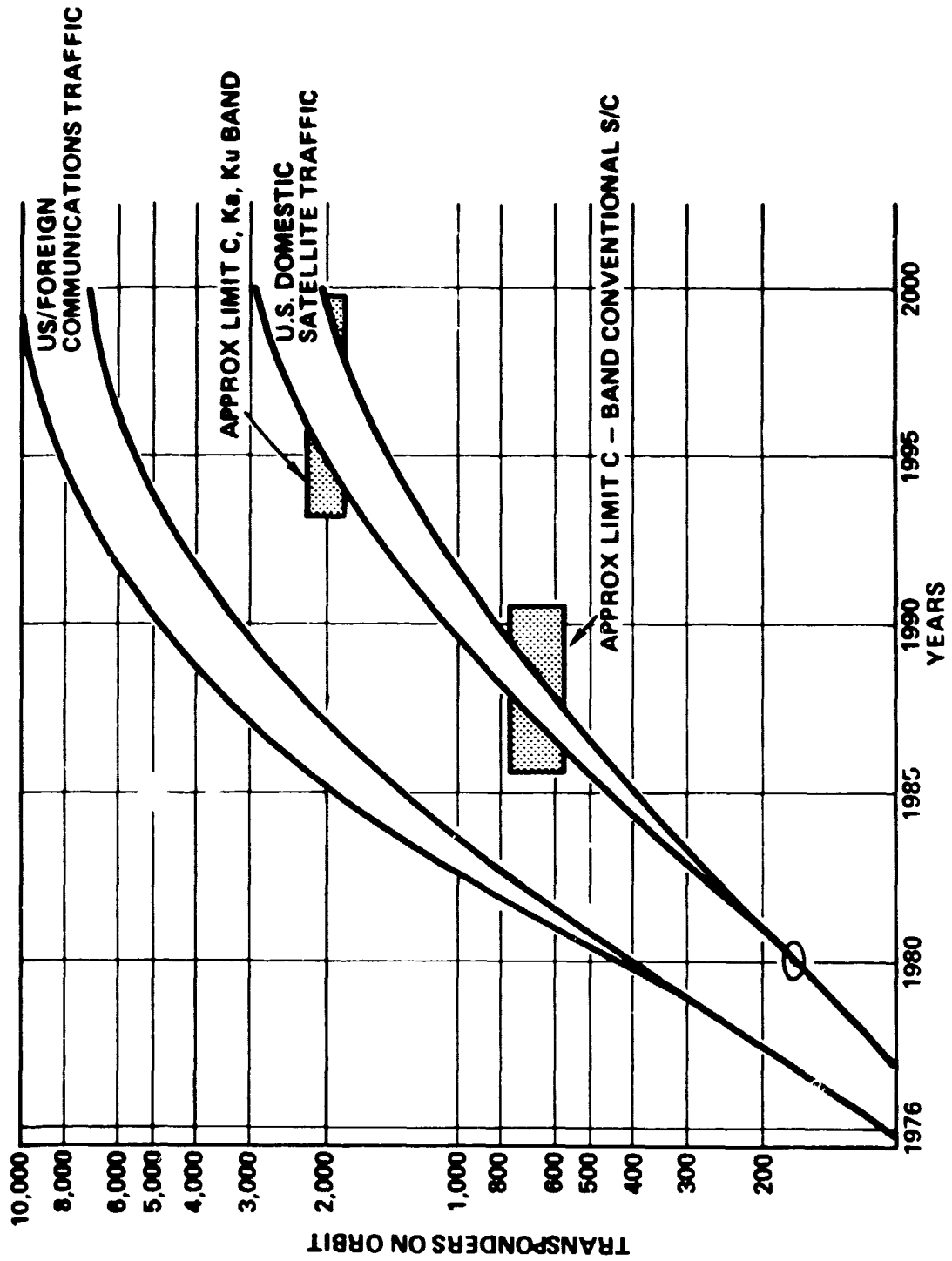
GEOSYNCHRONOUS COMMUNICATIONS MARKETS  
NASA 1980 FORECAST

Communications 21 has made an extensive review of literature relating to satellite communications demand and forecasts. Additionally, their survey requested comment on several of the more highly quoted studies. Of these, the NASA 1980 forecast is the most respected and is still considered to be a valid forecast.

# GEO SYNCHRONOUS COMMUNICATIONS MARKET NASA 1980 FORECAST



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## ASSUMPTIONS FOR COMMERCIAL COMMUNICATIONS

For the following analysis, these assumptions apply:

1. The NASA 1980 forecast of transponders on orbit through 2000 is a valid projection for present planning.
2. The 30/20 GHz band will be phased into operating equipment starting in 1990.
3. There will not be any communications platforms that carry numerous antennas and weigh more than 10,000 lbs. before 2000. There will be satellites that broadcast to mobile receivers and other small terminals making large and precise spacecraft antennas necessary.
4. About 1/3 of international and all domestic communication satellite launches will be performed by means of the STS.

Use of higher frequency bands will allow accommodation of more "equivalent 36 Mhz transponders" per satellite. The very great projected increase in requirements for "transponders", however, would still make necessary an increase in satellite launches per year. This can be off-set by a move away from smaller (delta class) satellites toward the larger ones (Atlas and IUS classes). It is postulated that market forces will indeed make this come about.

## ASSUMPTIONS FOR COMMERCIAL COMMUNICATIONS



- NASA 1980 FORECAST OF TRANSPONDERS ON ORBIT THROUGH 2000 IS A VALID PROJECTION FOR PLANNING (WAS VERIFIED DURING STUDY)
- 30/20 GHz BAND WILL BE PHASED INTO OPERATION STARTING IN 1990
- NO LARGE COMMUNICATION PLATFORMS (>10,000 LBS) ARE DESIRED BEFORE 2000
- SATELLITES WILL BE REQUIRED TO BROADCAST TO MOBILE (SMALL) RECEIVERS REQUIRING LARGE, PRECISE SPACECRAFT ANTENNAS
- ABOUT 1/3 OF ALL INTERNATIONAL AND ALL DOMESTIC COMM SATELLITE LAUNCHES WILL BE ON STS

SPACE STATION BENEFITS

These five benefits are expanded on the following charts.

## SPACE STATION BENEFITS

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THE SPACE STATION WILL SERVE COMMERCIAL COMMUNICATIONS IN FIVE WAYS:

1. COMMUNICATION SYSTEMS DEVELOPMENT TESTING
2. LARGE COMMUNICATION SATELLITE ASSEMBLY
3. COMMUNICATION SATELLITE TRANSSHIPMENT TO GEO
4. AROTV LEO TO GEO LAUNCHES
5. AROTV AIDED GEO SATELLITE SERVICING

## COMMERCIAL COMMUNICATIONS SYSTEM ELEMENT TEST

A number of technologies will be advanced in the process of providing for more efficient space communication systems. Most of these will require testing in space because the test cannot be run practically on earth. Low earth orbit testing is satisfactory, making the Space Station an important part in this development process. Some of the technological developments needed are as follows:

1. Shape of reflector surfaces and feed-to-reflector interfaces, which are affected by design shape concepts, manufacturing techniques, deployment positioning, dynamic flexibility, and thermal distortions. This technology also includes testing of side-lobe interference, broadening, and cross polarization that affect RF beam quality.
2. Controls for stabilizing large structural disturbances that affect RF beam quality, including rapid reconfiguration.
3. Improvements in the accuracy of attitude control for pointing and stability.
4. Development testing of very linear wideband transponder amplifiers for 4, 11, and 12 GHz and above.
5. Testing of bandwidth compression techniques for voice, image, and data transmission, including efficient channel coding techniques for highspeed, high-volume, and low-BER data streams.

The primary requirement is for mounting of a large earth pointed antenna (30M). Also required is mounting, power, cooling and control of experimental electronic equipment; sizes and power usage are nominal.

## COMMERCIAL COMMUNICATIONS SYSTEM ELEMENT TEST



### MISSION OBJECTIVES:

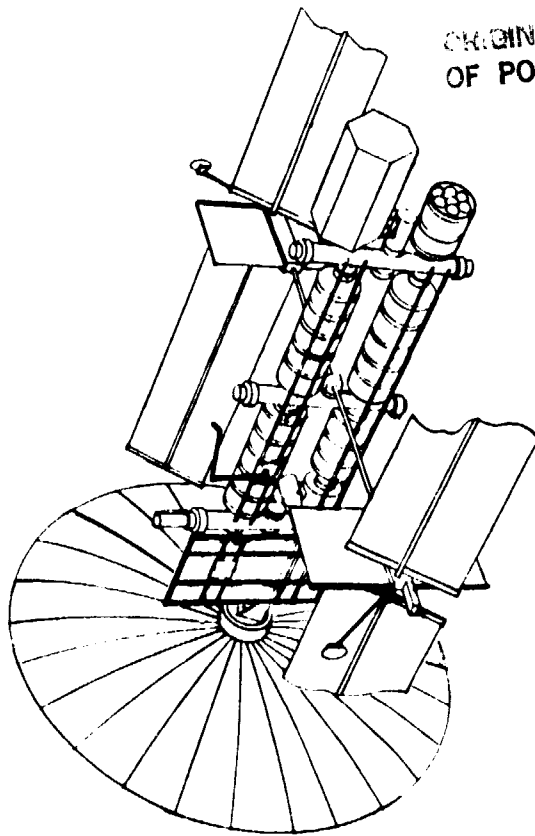
- TEST LARGE ANTENNA, ARRAY POINTING, RADIATION PATTERNS
- TEST LARGE STRUCTURE CONTROLS FOR ATTITUDE DYNAMICS AND FORM FACTOR
- MEASURE TRANSPONDER AND BEACON CHARACTERISTICS IN THE 11 TO 94 GHz FREQUENCY RANGE

### USERS:

- COMMERCIAL COMMUNICATION SYSTEM DEVELOPERS

### SPACE STATION SCENARIO:

- ELEMENTS ARE SUPPORTED BY SS DURING ERECTION, ASSEMBLY, AND TEST
- REQUIRES SUPPORT, POWER, LARGE CLEAR VOLUME, EVA ACTIVITIES, POINTING AND DATA HANDLING



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### ANTICIPATED PAYOFFS:

- TEST OF ELEMENTS, OTHERWISE UNTESTABLE PRIOR TO OPERATIONAL COMMITMENT
- LOW COST COMMERCIAL DEVELOPMENT OF IMPROVED COMMUNICATION CAPABILITIES

## COMMERCIAL COMMUNICATIONS SYSTEM ASSEMBLY AND TEST

Very large communication satellites will eventually be required for service to mobile receiving stations and for high power direct broadcast services. These satellites are envisioned as having antennas, solar arrays and deploying structures too large for a single Shuttle load or requiring lengthy time on orbit for deployment, erection, testing, and adjustment. The Space Station will provide facilities for these activities then integrate the satellite with an OTV for transfer to GEO. Requirements are for manipulators, EVA support and an adjacent space for erection and test of the satellite. An advantage of the Space Station is the capability to test the system prior to boosting the system to GEO.

## COMMERCIAL COMMUNICATIONS SYSTEM ASSEMBLY AND TEST



REFLECTOR DIAMETER: 52 METERS

### MISSION OBJECTIVES:

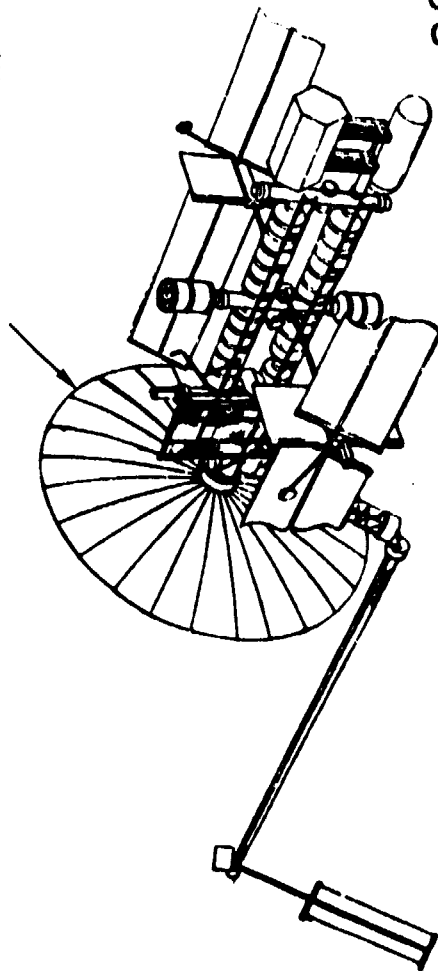
- ASSEMBLE AND TEST VERY LARGE COMMUNICATION SYSTEMS PRIOR TO COMMITMENT TO GEO

### USERS:

- COMMERCIAL COMMUNICATION SYSTEM OPERATORS

### SPACE STATION SCENARIO:

- RECEIVES ELEMENTS OF THE SYSTEM FROM SHUTTLE, ASSEMBLES ORBITAL SEGMENT, PERFORMS SYSTEM TEST, INTEGRATES IT TO OTV, SERVICES OTV AND LAUNCHES TO GEO
- REQUIRES CLEAR VOLUME, EVA AND ERECTION EQUIPMENT, FUEL SERVICING, LAUNCH CONTROL SYSTEM



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### ANTICIPATED PAYOFFS:

- REDUCED STRESS ON THE SYSTEM DUE TO DENSE PACKAGING IN SHUTTLE AND LOW G TRANSFER TO GEO
- OPPORTUNITY FOR ON-ORBIT TEST PRIOR TO COMMITMENT TO GEO
- AVAILABILITY OF VERY LARGE COMMUNICATION SYSTEMS
- REDUCED COST PER TRANSPONDER YEAR ON ORBIT

## COMMERCIAL COMMUNICATIONS SATELLITE TRANSSHIPMENT

It is possible to take advantage of the large LEO to GEO capability of the Centaur stage by assembling a number of communication satellites onto a carrier vehicle for joint orbital transfer. This mode also makes it possible to use the higher Shuttle packing density that is achievable with the Space Station. Both factors provide cost savings to the satellite operator. The frequent flights to the Space Station could make Shuttle launch scheduling easier, however, there will be delays at the Space Station while a barge load is accumulated and assembled.

## COMMERCIAL COMMUNICATIONS SATELLITE TRANSSHIPMENT



### MISSION OBJECTIVES:

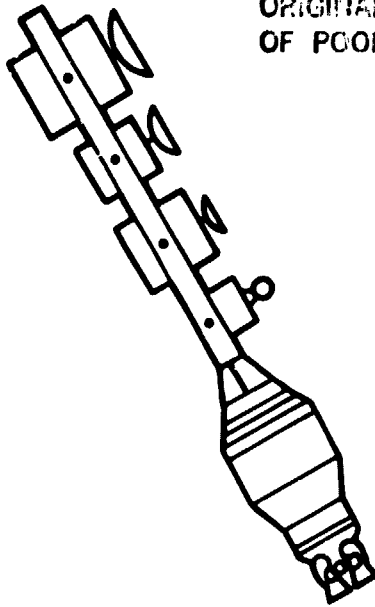
- ASSEMBLE COMMUNICATIONS SATELLITES IN LEO TO PROVIDE LOWERED COST TRANSFER TO GEO

### USERS:

- COMMERCIAL COMMUNICATION SATELLITE OPERATORS

### SPACE STATION SCENARIO:

- RECEIVES SPACECRAFT, BARGE AND OTV FROM SHUTTLE FLIGHTS; ASSEMBLES THEM; CHECKS OUT SATELLITES AS REQUIRED; CHECKS OUT OTV AND LAUNCHES TO GEO
- REQUIRES BERTHING, STORAGE AREA, ASSEMBLY AREA, LAUNCH FACILITIES



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### ANTICIPATED PAYOFF:

- LOWER COST FOR LAUNCH TO GEO

## COMMUNICATIONS SATELLITE

### SPACE STATION BENEFITS ANALYSIS LAUNCH FORECAST

This chart compares launching the required communications spacecraft to GEO by barging from a Space Station with their launch using the STS without the Space Station

The first five columns list the number of spacecraft, of various classes, that are needed to satisfy the transponder requirements established by the NASA forecast. This conversion from transponders to spacecraft is made in the manner of the 1981 NASA study of Shuttle launch requirements. It is assumed that the U.S. will capture 1/3 of all foreign satellite launches and will fly all U.S. satellites. A modification is made from the AIAA forecast toward more spacecraft of the large classes and less of the smaller ones.

To establish the number of STS flights without a Space Station, it is assumed that the Centaur stage is available and that up to 12,000 lbs. of spacecraft can be carried and assembled onto the loaded Centaur stage in one Shuttle flight.

To establish the number of STS flights needed when barging from the Space Station is used, it is assumed that the Centaur can launch up to 35,000 to GEO from the Space Station orbit. One of these STS flights is used to bring up the barge structure and the Centaur stage.

As shown, some reduction in STS flights is possible with the Space Station. Obviously if barging on the STS launches was eliminated, the Space Station based barging would show far greater savings in number of STS flights.

# COMMUNICATIONS SATELLITE SPACE STATION BENEFITS ANALYSIS LAUNCH FORECAST



	SATELLITES LAUNCHED PER YEAR SPACECRAFT CLASS (1)				TOTAL	BARGED STS FLIGHTS WITHOUT SPACE STATION (2)	STS FLIGHTS WITH SS AND BARGING (3)
	DELTA	ATLAS	IUS	CENT.			
1990	8	5	4		17	4	4
1991	6	4	5		15	3	3
1992	4	3	6		13	3	3
1993	4	3	6		13	3	3
1994	3	4	7		14	3	3
1995	2	3	8		13	4	3
1996	2	3	8		13	4	3
1997	2	2	8	1	13	4	3
1998	1	2	8	1	12	4	3
1999	1	2	7	2	12	5	3
2000	1	2	6	3	12	5	3

(1) CAPTURE OF TRAFFIC ASSUMED TO BE ALL U.S. SPACECRAFT & 1/3 FOREIGN SPACECRAFT  
CLASS WT. DELTA - 1200 LBS; ATLAS - 2000 LBS; IUS - 5000; CENTAUR - 10,000

(2) FLIGHTS MANIFESTED AT 1 CENTAUR STAGE PLUS  $\leq$  12,000 LBS OF SATELLITES

(3) BARGE CARRIES A NUMBER OF SPACECRAFT AT ONE TIME,  $\leq$  35,000 LBS  
BARGE AND STAGE ON ONE STS FLIGHT

COMMUNICATIONS SATELLITE  
SAVINGS WITH TRANSSHIPMENT AT SPACE STATION  
VERSUS STS ALONE

Costs for the proceeding launches are established as shown with 1984 cost for STS launch of \$86M, an assumed cost for the Centaur stage of \$42M, and cost for each barge of \$10M. Stages and barges are assumed to be expended by each flight. Transshipment of spacecraft from the Space Station does not provide significant savings until a number of the larger spacecraft are being used, about 1995.

In the Launch Forecast chart, the 10,000 lb. satellite (called Centaur class) start to phase into use in 1997. For this analysis, it is assumed that these spacecraft will have large appendages, antennas and solar arrays, and will require on-orbit assembly. This task is assumed to require 3-days. When performed without use of the Space Station, it requires three extra on-orbit days for the Orbiter, priced at \$1M per day.

COMMUNICATIONS SATELLITE  
SAVINGS WITH TRANSSHIPMENT AT SPACE STATION  
VERSUS STS ALONE



(ALL COSTS IN MILLIONS OF 1984 \$)

	COST WITHOUT SPACE STATION (1)	COST WITH SPACE STATION (2)	TRANSSHIPMENT SAVINGS	ASSEMBLY SAVINGS (3)	TOTAL SAVINGS
1995	512	414	98		98
1996	512	414	98		98
1997	512	414	98	3	101
1998	512	414	98	3	101
1999	640	414	226	6	232
2000	640	414	226	9	235
TOTAL			844	21	865

AVERAGE SAVINGS PER YEAR = \$129.5M

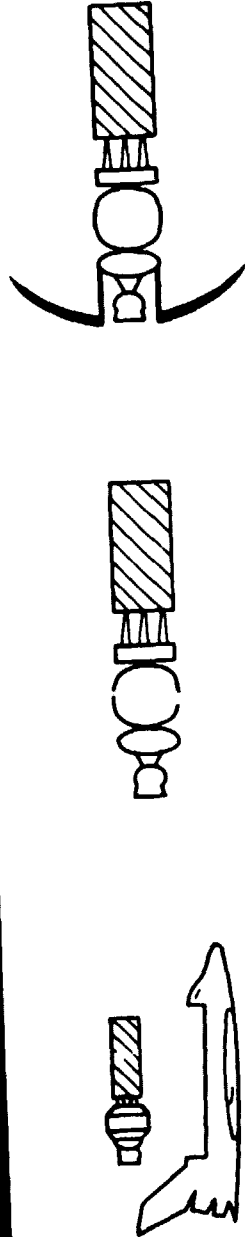
- NOTES:**
- (1) SHUTTLE LAUNCH \$86M, CENTAUR \$42 (86 + 42 = \$128 M/FLY FLT)
  - (2) SHUTTLE LAUNCH \$86M, CENTAUR \$42M, BARGE \$10M (86 + 42 + 10 = \$138 M/FLT)
  - (3) ADDITIONAL STS COST DUE TO 3 EXTRA DAYS ON ORBIT PER SPACECRAFT ASSEMBLY AT \$1 M/DAY

## OPTIONS FOR TRANSPORT TO GEO

In the SS benefits studies, three options for transportation to geosynchronous orbit are considered: 1) an STS carried upper stage using cryogenic propellants, 2) a space station based returnable OTV (ROTV) that returns using all propulsive maneuvers, and 3) an ROTV that returns from geosynchronous orbit using a perigee aerobrake maneuver to provide a portion of the mission velocity requirement (referred to as an AROTV). The representative characteristics and performances used in the study for each of these vehicles are shown in the facing chart. Each vehicle is assumed to have a payload capability of 12,000 lbs. This value is an estimated limit for the STS deployed geo-payloads. As indicated, the limit is due to STS cargo bay volume rather than lift capability. The ROTV's are sized to have this same payload capability to ease comparison. Note that the AROTV is heavier unloaded than the ROTV because of the aerobrake. The all-propulsive ROTV requires more propellant than the AROTV, however. Although it is conceivable that ROTV's could be deployed from the Shuttle or possibly left on orbit between Shuttle flights, it is judged in this study that the practical use of returnable OTV's require the availability of a permanent manned servicing facility in low earth orbit.



## OPTIONS FOR TRANSPORT TO GEO



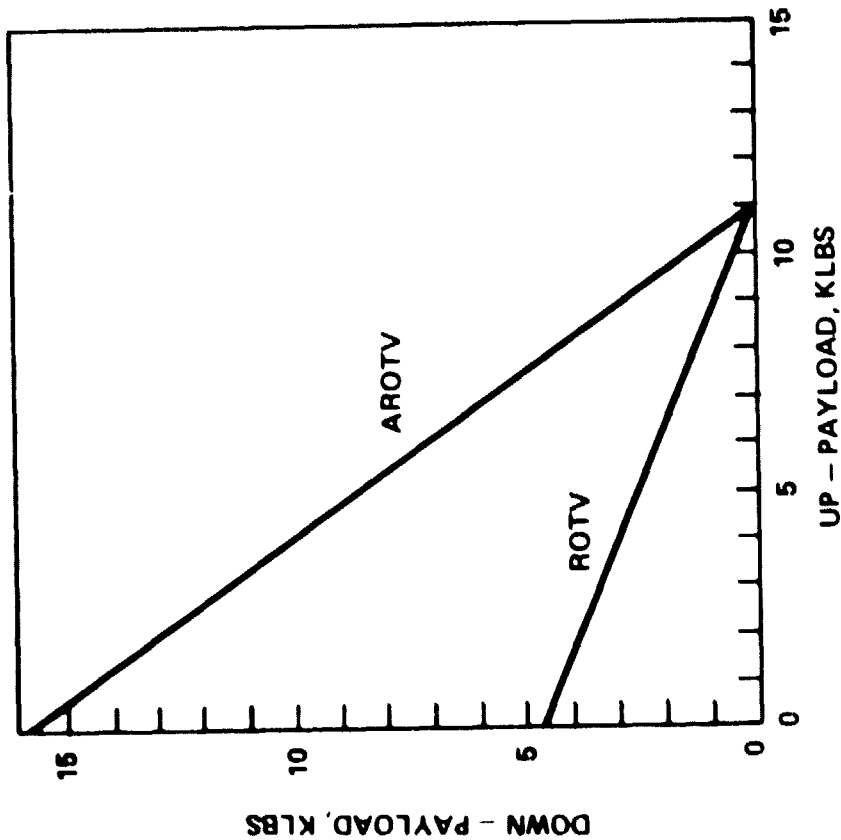
OPTION	STS-CARRIED CRYO STAGE	ALL-PROP ROTV	AERO-BRAKED ROTV
PAYLOAD, LBS	12,000	12,000	12,000
ISP, SEC	460	480	480
PROPELLANT, LBS	28,600	35,800	31,200
EMPTY VEHICLE, LBS	6,000	3,600	5,000
CARGO BAY LENGTH, FT	23	NA	NA
PERFORMANCE LIMIT	CARGO BAY VOL.	ROTV SIZING	ROTV SIZING

- 12,000 LBS PAYLOAD, PRACTICAL LIMIT FOR STS CARRIED CRYO STAGE
- ROTV'S SCALED TO 12,000 LB PAYLOAD FOR EASY COMPARISON

## RIDE SHARING TO/FROM GEO

A returnable OTV can carry payloads to and from geosynchronous orbit. The total payload capability is limited by the PGTV performance and can be apportioned between "up-payload" and "down-payload" as indicated in the accompanying chart. The two PGTV up-payload capabilities are, as intended, equal. The down-payload of the AROTV is much greater than the corresponding PGTV capability because of the efficiency of the aerobrake maneuver; in fact, the AROTV can return more payload (~15,000 lbs.) than it can lift to geo-orbit. As indicated on the graph, the payloads can be apportioned and likewise the costs of the flight can be apportioned according to the fraction of the vehicle capability that is being devoted to the particular payload.

# RIDE SHARING TO/FROM GEO



AROTV. AERO BRAKED ROTV	
ROTV. ALL-PROP ROTV	
	AROTV
DRY WT, LBS	3,600
ISP, SEC	400
UP - ΔV, fps	14,000
DOWN - ΔV, fps	14,000
	6,000

- AROTV RETURNS 3 X PAYLOAD OF ROTV
- PAYLOADS TO/FROM GEO CAN SHARE RIDE
- COSTS CAN BE PRO RATED VS ALLOCATED PROPELLANT

## COST OF TRANSPORTATION TO AND FROM GEO ORBITS

Costs in 1984 \$ are estimated for all of the transportation modes and options under consideration. The costs consist of, as indicated, OTV or stage hardware costs and STS transportation costs. In the case of the upper stage, the hardware cost is for the purchasing a new, expendable vehicle (\$42M). Hardware costs for the ROTV and AROTV (\$10M and \$7M, respectively) include amortized RDT&E plus new ROTV production and per-flight hardware costs (e.g., replacement of the aerobrake, if needed). No SS servicing costs are assessed in keeping with the "free space station" benefits<sup>\*</sup> evaluation approach. STS transportation cost is based on an \$86M price per launch, 75 Klb. lift capability, and for the ROTV's, an overall 92% load factor. 15% FSE<sup>\*\*</sup> is accounted for plus, in the case of the ROTV's, 10% propellant tankage weight. The two ROTV costs are very comparable and are both a significant improvement vs. the STS carried cryo-stage. The value of the AROTV over the ROTV enters in when evaluating the transportation rates of cost per pound of payload as shown in the next chart.

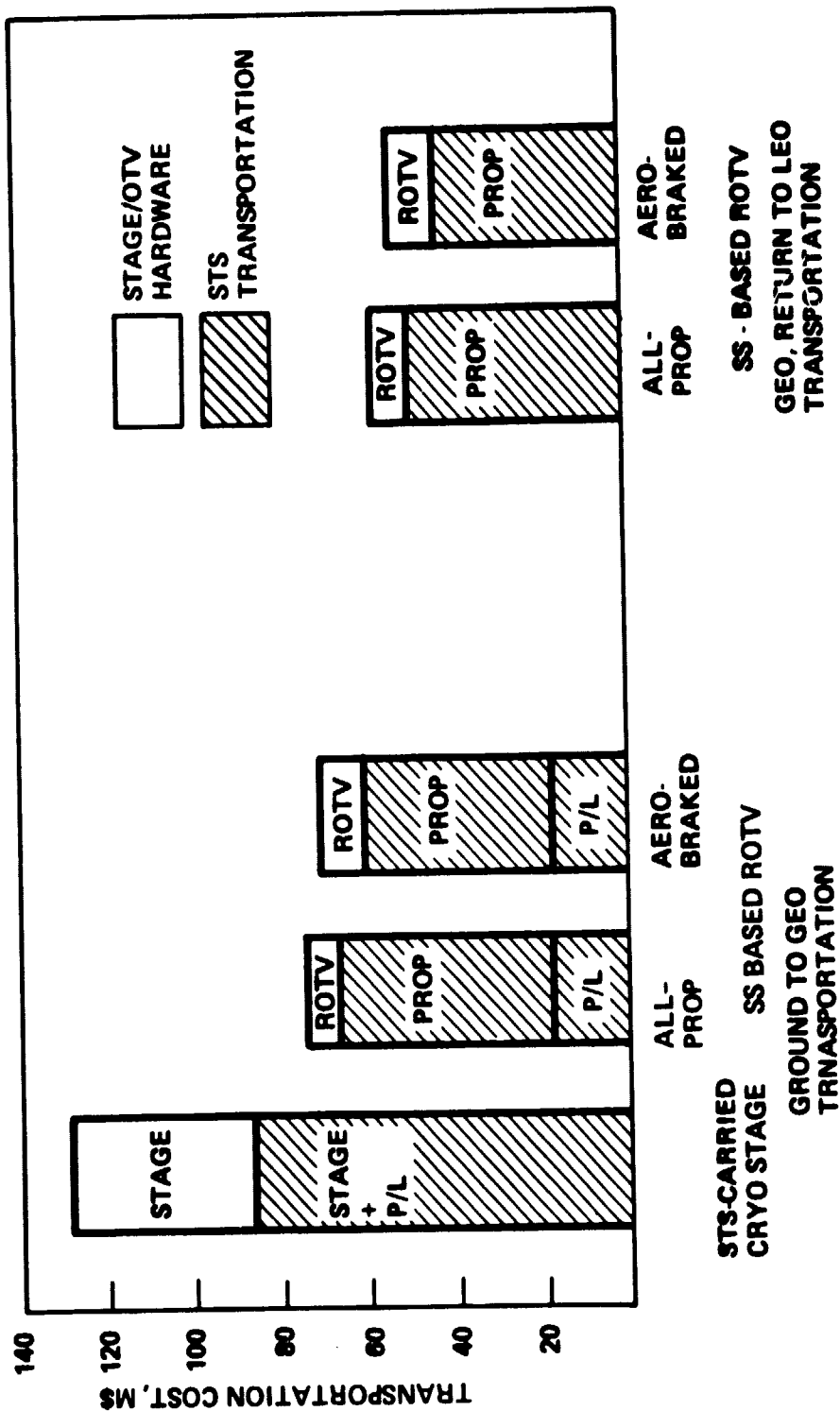
\* Cost of the Space Station is weighed against total benefits in the cost splinter meeting document.

\*\* FSE: Flight Support Equipment



Program Management  
Division  
TRW Space &  
Technology Group

## COST OF TRANSPORTATION TO AND FROM GEO ORBITS



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ROTV's REDUCE COST BY:  
- REUSING HARDWARE  
- AVOIDING STS VOLUME CONSTRAINT

## TRANSPORTATION RATES

The costs from the preceeding chart and the previously indicated payload capabilities are used to calculate transportation charging rates for each of the transportation modes of interest. A strong improvement of the ROTV's over the Shuttle upper stage and a greater than 3 to 1 improvement in return-from-GEO cost afforded by the AROTV over the ROTV are observed. Note that these rates are applicable to either fully loaded flights or they can be used as prorated costs in the case of shared loads, either to-or from-geosynchronous orbit.

## TRANSPORTATION RATES

<u>CASE</u>	<u>PAYLOAD, LBS</u>	<u>COST, M\$</u>	<u>RATE, K\$/LB</u>
<b>TO GEO</b>			
STS/CRYO STAGE	12,000	128	10.7
ALL-PROP ROTV	12,000	73	6.1
AROTV	12,000	70	5.8
<b>FROM GEO</b>			
ALL-PROP ROTV	4,500	56	12.4
AROTV	15,300	53	3.5

- ROTV'S REDUCE COST OF TRANSPORT TO GEO BY 40%
- AROTV INTRODUCES OPTIONS FOR REPAIRING/RETURNING GEO SATELLITES AT ACCEPTABLE COSTS

## GEO-SATELLITE REPLACEMENT VS. SERVICING

The AROTV provides the potential for lower cost return-transportation from geo-orbits. This in turn introduces repairing and servicing of geo-satellites as a possible cost effective option. Two approaches can be considered: 1) returning a geo-satellite to low-earth orbit and servicing it at a space station, and 2) repairing the satellite or satellites at their geosync stations using an AROTV-transported automated repair vehicle. Both approaches have been evaluated; this chart details the costs of the repair-at-LEO option, a simpler, although not necessarily less costly approach than repairing at GEO. The cost is compared to today's satellite maintenance approach of replacing the satellite when it has failed or is nearing the end of its lifetime.

Both the replacement and service cases' costs are composed of transportation and satellite hardware and service costs. The transportation cost is based on the preceeding evaluations. The remaining costs are reasonable estimates used to assess the possible savings. SS servicing cost has been neglected in estimating the benefit.\* The estimated savings and hence the benefit of satellite servicing using the SS based AROTV is \$56M.

\* SS costs are weighed against total benefits in the cost splinter meeting document.

**GEO-SATELLITE REPLACEMENT VS SERVICING  
AT LEO  
( COSTS IN M\$ FOR TYPICAL 5,000 LB VEHICLE)**



	<u>REPLACE SATELLITE</u>		<u>SERVICE SATELLITE</u>
REPLACE H/W	85.0	ORU H/W	8.5
STS TRANSPORT TO LEO	7.2	GROUND SUPPORT	9.5
AROTV TRANSPORT LEO → GEO	21.8	STS ORU TRANSPORT	0.7
TOTAL	114.0	AROTV TRANSPORT GEO → LEO	17.5
		AROTV TRANSPORT LEO → GEO	21.8
		TOTAL	58.0

**SAVINGS FOR SERVICING    \$56 M**

## COMPARISON OF REPAIR AT LEO AND REPAIR AT GEO STRATEGIES

The cost savings of repairing geo-satellites is evaluated in terms of variations due to satellite weight and the choice of repair strategy; either using the space station at LEO or an automated repair vehicle at GEO. The variation with respect to weight accounts for cost variation by weight in the satellite hardware (assumed to be \$17K/lb.) and in the transportation to and from GEO.

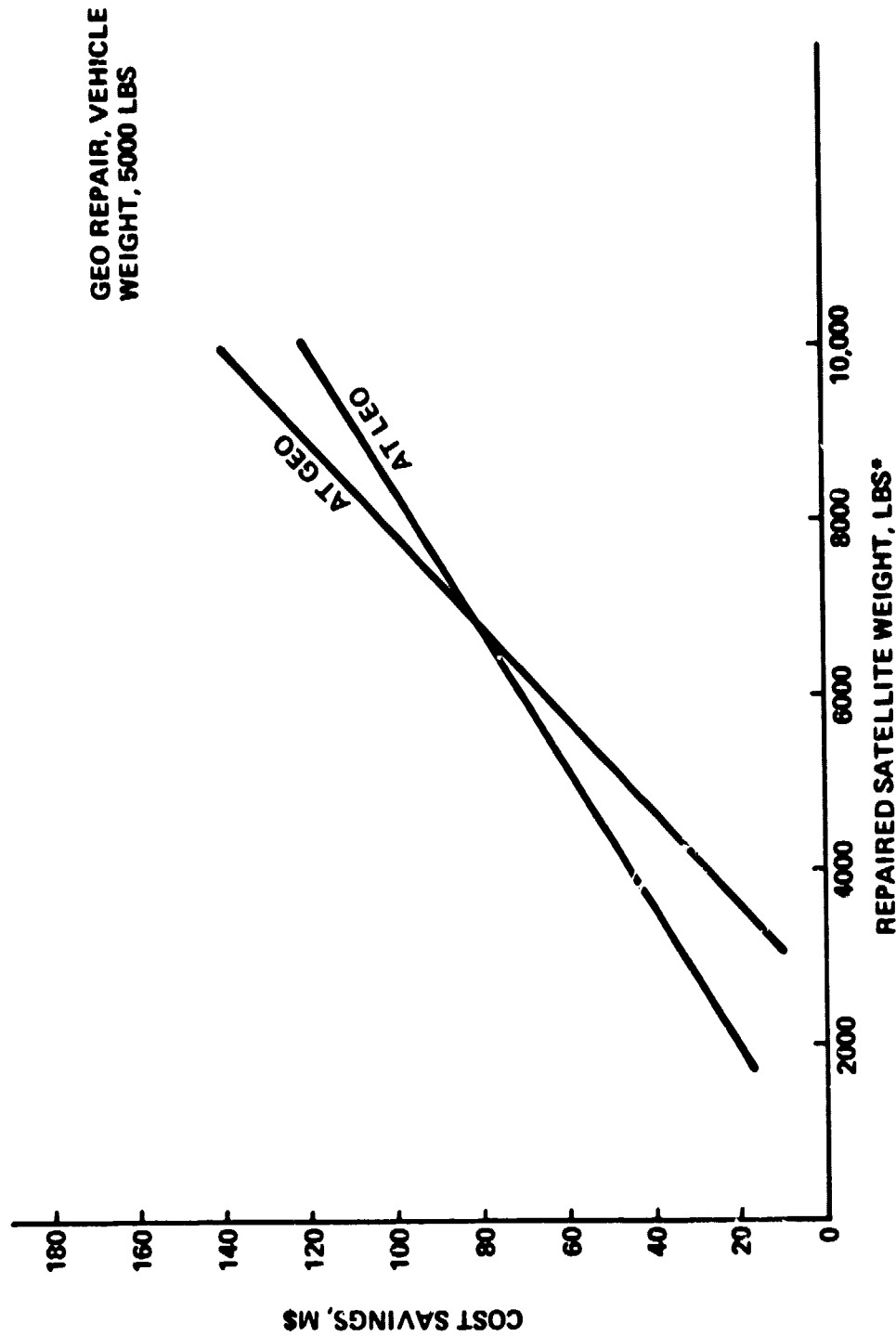
The chart indicates:

1. Repair of small, 1000-2000 lb. satellites is most likely marginal to not cost effective.
2. Returning satellites to LEO for repair is more cost effective than repairing at GEO, for satellites in the 2000 lb.-5000 lb. range; whereas, for satellites above 10,000 lb., the repair at GEO approach is favorable.

The second conclusion can be extended to multiple satellites where the "satellite weight" can serve as total weight for the multiple satellites. Thus, repair at GEO becomes favorable if a sufficient number of satellites of given size are repaired in a single repair mission. These results give rise to an evolutionary approach where satellite return to LEO and repair is employed first, giving way near the end of the decade to the repair of large and/or multiple satellites in geosynchronous orbit. This approach is based on the assumption that repair and servicing at GEO is a technologically more demanding task than retrieving satellites from GEO and repairing at LEO.



## COMPARISON OF REPAIR AT LEO AND REPAIR AT GEO STRATEGIES



\*SINGLE SATELLITE OR TOTAL FOR MULTIPLE SATELLITE REPAIRS

## SAVINGS FOR TYPICAL YEAR IN MISSION MODEL (1997)

The results of the preceeding analysis are applied to the space station mission model for a typical year, 1997. The effected missions are two large commercial communications satellite categories, the 2,000 lbs. and 5,000 lbs. class communications satellites, and the generic mission of DoD geosynchronous satellites with a representative weight of 6,000-7,000 lbs. The benefits of the SS-based ROTV and the servicing of geo-satellites at low-earth orbit are evaluated. The cost savings are calculated using the transportation rates given on page 38 and repair savings weight sensitivities given on page 42. The benefits are calculated so that they are additive, i.e., servicing vs. replacement assumes AROTV transportation rates.

Benefits due to these savings are \$483M and \$824M per year, respectively, for ROTV transportation and satellite servicing. The servicing savings are calculated using an assumed division between the number of replacement vs. new capability launches as shown in the chart. These benefits accrue in the cost benefits analysis starting in 1995 since it is assumed that the attendant AROTV and satellite servicing technologies will not be ready until then.

# SAVINGS FOR TYPICAL YEAR IN MISSION MODEL (1997)



APPLICABLE MISSIONS	NO SERVICING		SERVICING	
	LAUNCHES		LAUNCHES	SERVICES
COMMUNICATIONS: 2000 LB CLASS	2		0	2
COMMUNICATIONS: 5000 LB CLASS	8		2	6
DoD: 6000 - 7000 LB CLASS	8		2	6
TOTAL LAUNCHES/SERVICES	18		4	14
TOTAL WEIGHT, LBS	98,600		23,200	73,600

SAVINGS:	1. AROTV VS STS/CRYO STAGE	\$483M
	2. SERVICING VS REPLACEMENT	\$824M

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## **Commercial Remote Sensing**

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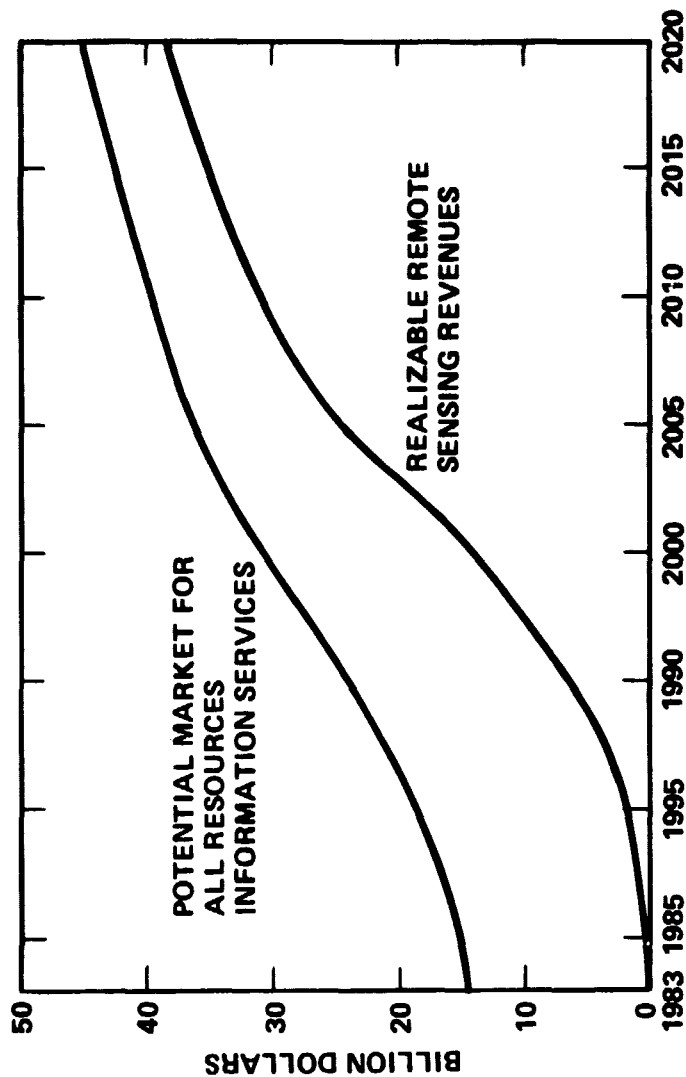
**TRW Supported by Terra Mar Associates and  
AI Loomis Associates**

## PROJECTED REALIZABLE REVENUES FOR REMOTE SENSING

The data on this chart are from the Terra-Mar Associates report "Markets for Remote Sensing Data, 1980-2000", November, 1982. This report\*(provided to TRW under subcontract) is particularly valuable because it clearly traces the derivation of the data and makes a strong case for a differentiation between the total potential market and those revenues that are realizable.

\*Delivered to NASA as an appendix to our Final Report.

## PROJECTED REALIZABLE REVENUES FOR REMOTE SENSING\*



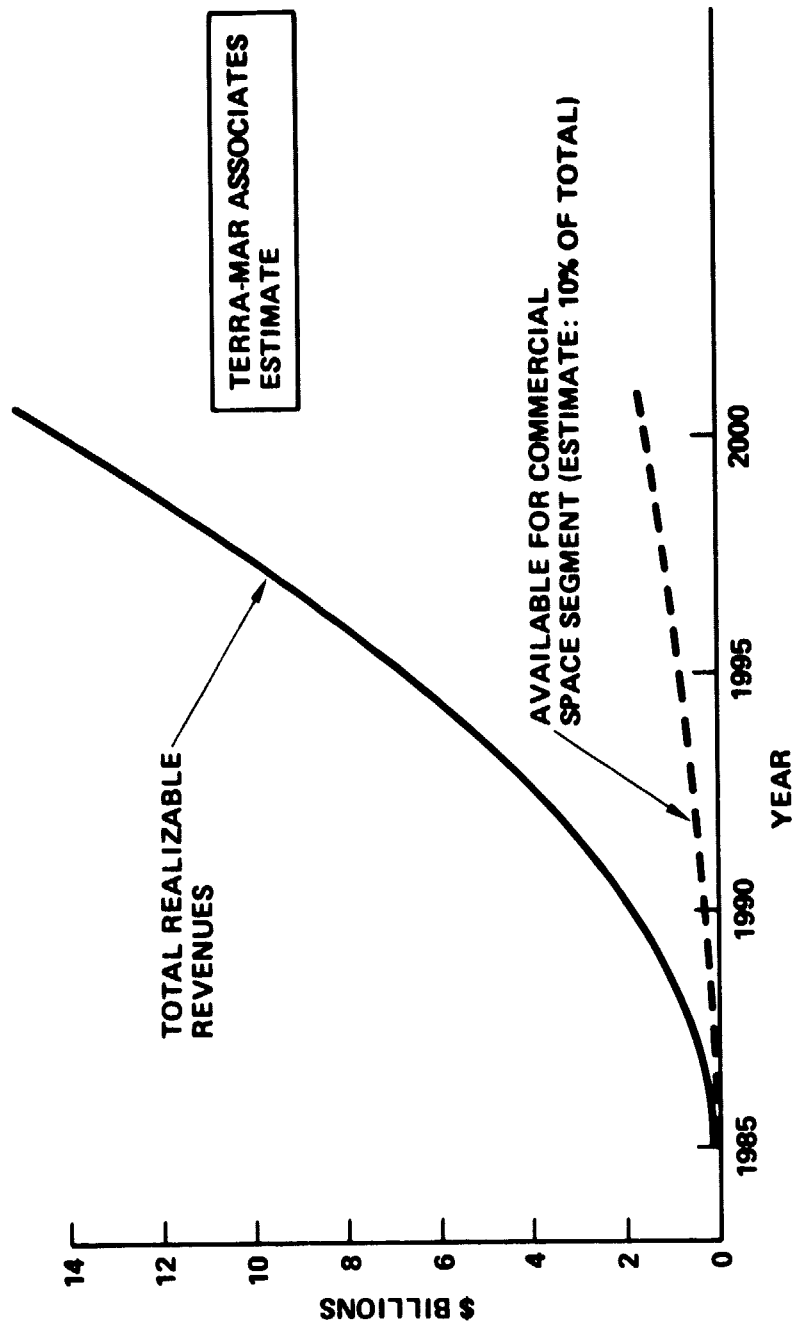
### 1990 MARKET FOR ALL RESOURCES INFO SERVICES

OIL AND MINERAL	23%
LAND USE PLANNING	22%
FORESTRY	11%
AGRIBUSINESS	
CROPS	27%
LIVESTOCK/RANCHES	7%
SERVICES	7%
MARINE RESOURCES	3%

SATELLITE REMOTE SENSING FOR  
EARTH AND OCEAN SENSING MARKET  
(NOT INCLUDING WEATHER)

The curve of realizable revenues is from the Terra-Mar Associates report. TRW has added the curve for those revenues available to the space segment which are estimated as 10% of realizable revenues. The 10% figure is derived from the present trend in value-added companies who work with digital data to price their products about an order of magnitude higher than they pay for the original data.

# SATELLITE REMOTE SENSING FOR EARTH AND OCEAN SENSING MARKET (NOT INCLUDING WEATHER)



- COMMERCIAL MARKET IS LARGELY IN VALUE-ADDED SERVICES

## HISTORY OF REMOTE SENSING MARKET PROJECTIONS

A number of studies have been made to assess the economic benefits that can accrue from operation of Landsat type satellite remote sensing systems. The table lists the most quoted studies and their, bottom line, total benefits projections. The spread of the magnitude of the benefits is a measure of the many factors that might be, but are not always, considered in such a study.

We have not attempted a similar broad study but instead have made spot checks on some areas of the realizable market. We have been able to verify the general level of several of Terra-Mar Associates' estimates of total data expenditure. The reduction of these levels to their "Realizable Market Predictions", involves some estimated coefficients which might be questioned. However, revenues of the size estimated are believed possible when one considers that most of this commercial business will be developed by value-added activities.



## HISTORY OF REMOTE SENSING MARKET PROJECTIONS

<u>CORP/AUTHOR</u>	<u>DATE PUBLISHED</u>	<u>ANNUAL MARKET (\$ BILLION)</u>		<u>REMARKS</u>
		<u>U.S.</u>	<u>WORLDWIDE</u>	
EARTH SAT. CORP/ BOOZE ALLEN	1974	0.13 (1985)		LANDSAT 1, RESOURCE SURVEIL- LANCE ONLY
ECON INC.	1974	(1975)	3.3-6.3	LANDSAT 1, BROAD APPLICATION
ABT ASSOCIATES	1981	5-10 (1982)	30-35	NEW SENSORS, AGGRESSIVE MAR- KETING, TOTAL BENEFITS
QAO CORP.	1981	3-5 (1982)		POTENTIAL MARKET FOR DATA
TERRA-MAR ASSOCIATES	1982	0.35 (1985)	0.55	} REALIZABLE MARKET FOR DATA
		1.54 (1990)	3.82	
		12.6 (1995)	21.0	

## REMOTE SENSING USER CONTACTS

During the course of the study, TRW has interacted with current end users of remote sensing data, with interpretive and/or predictive consultants, and with value-added concerns in several areas. These areas include petroleum exploration, minerals exploration, cartography, agriculture, forestry, ocean shipping and fishing, deep ocean mining, offshore platform operations, Arctic operations, and global weather forecasting for marine and agricultural interests. All of these users and value-added companies have used satellite data either directly in company operations or have participated in demonstrations. All believe that the satellite remote sensing data they have used have been of value, and all would like more data of different types to become available in the future for their commercial (i.e., not research) use.

## REMOTE SENSING USER CONTACTS

<u>NAME</u>	<u>ORGANIZATION</u>	<u>RELATIONSHIP TO REMOTE SENSING</u>
MICHAEL I. DAILY	MOBILE OIL CO.	OIL AND MINERALS EXPLORATION
KURT Z. HAGEN	PHILLIPS PETROLEUM CO.	OIL AND MINERALS EXPLORATION
PAUL HARRISON	CITIES SERVICE OIL CO.	OIL AND MINERALS EXPLORATION
HARRY STEWART	SUN OIL CO.	OIL AND MINERALS EXPLORATION
TERRY LEHMAN	ARCO	OIL AND MINERALS EXPLORATION
MICHAEL McGUIRE	AMOCO PRODUCTION CO.	OIL AND MINERALS EXPLORATION
ROBERT VINCENT	GEOSPRECTRA INC.	VALUE ADDED CO. (GEOLOGY)
FRED B. HENDERSON	GEOSAT COMMITTEE	TECHNICAL LOBBYING
G. ROBINSON BARKER	ST. REGIS PAPER CO.	FOREST MANAGEMENT
FRANK G. LAMB	EASTERN OREGON FARMING CO.	AGRICULTURE
A. RICHARD BALDWIN	CARGILL, INC.	GRAIN TRADING
JOHN HAYES	GLOBAL SCIENTIFIC	VALUE ADDED CO. (OCEANOGRAPHY)
KEN RUGGLES	GLOBAL WEATHER DYNAMICS, INC.	VALUE ADDED CO. (WEATHER)
FRITZ SNIDEMAN	OCEAN ROUTES, INC.	OCEAN DYNAMICS AND WEATHER
PAUL WOLFF	OCEAN DATA SYSTEMS, INC.	VALUE ADDED CO. (OCEANOGRAPHY)
FRANK MARTINS	AMERICAN FISHING RESEARCH FOUNDATION	COMMERCIAL FISHING
JACK FUECHSEL	NATIONAL OCEAN INDUSTRIES ASSOCIATION	TECHNICAL LOBBYING
GILBERT WEILL	SPOT IMAGE U.S.A.	SATELLITE DATA SYSTEM
FREDERICK J. DOYLE	INT. SOCIETY FOR PHOTOGRAMMETRY & R. S.	TECHNICAL SOCIETY

## REMOTE SENSING SUMMARY CONCLUSIONS

A market already exists in weather prediction and a number of successful firms are operating in that market. A similar market is in existence in earth and ocean remote sensing but has been delayed in its development because of a lack of an assured flow of primary data.

However, a strong young value-added industry exists and has shown enough profit potential to acquire growth capital as needed. We believe that this industry will, as it matures, generate sufficient profits to enable private funding of the space segment as well.

The space station could assist in this maturing process by reducing the capital requirement for this space segment and hence reducing the cost of primary data. It also assists in assuring continued availability of this data.

## REMOTE SENSING SUMMARY CONCLUSIONS

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- A VERY SIGNIFICANT MARKET EXISTS NOW — READY TO BE EXPLOITED
- THE SPACE STATION ROLE:
  - TEND CO-ORBITING SATELLITES
  - USE MAN TO PERFORM SPECIAL TESTING AND ON-DEMAND DATA ACQUISITION
- MARKET WILL DEVELOP AS COMPUTER SERVICES, ADAPTING DATA FOR SPECIFIC USER GROUPS
- AFTER THE MARKET MATURES THERE WILL BE ADEQUATE FUNDING FOR THE SPACE SEGMENT
- THE SPACE STATION CAN SPEED MARKET MATURITY BY REDUCING DATA COST

## ASSUMPTIONS FOR COMMERCIAL REMOTE SENSING

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In order for private enterprise to take steps beyond data processing and value-added services and use the station capabilities for privately owned sensors and satellites, some conditions must be met. We make the following assumptions.

1. It is assumed that the U.S. government or a large commercial operator will continue the Landsat series and will continue to obtain meteorological data.
2. It is assumed that the planned French, ESA, Japanese, and Canadian programs provide data amenable to post-processing at a reasonable cost.
3. In order for the private sector to fly their own sensors or satellites, the cost of the space segment must be much lower than present costs for the space segment of the remote-sensing systems. It is assumed that use of the Space Station for carrying sensors, or for launching and tending small free-fliers, will provide such a decrease in cost.
4. It is assumed that the data obtained by a privately funded sensor will belong to the sensor owners for sale or for use in creation of a value-added product. It is assumed that the government will not restrict the sale of data from the private sensor.
5. In order for the private sector to finance their own sensors and satellites, the U.S. Government must not compete by flying similar sensors for their own use or for production of products for the open market.
6. It is assumed that a privately funded sensor or satellite would be afforded the same priorities of scheduling for launch, maintenance, data acquisition and transmissions, etc., as would government-owned sensors and satellites.

## ASSUMPTIONS FOR COMMERCIAL REMOTE SENSING



- U. S. GOVERNMENT OR COMMERCIAL OPERATOR WILL CONTINUE WEATHER SATELLITE AND LANDSAT SERIES TO ENABLE THE DATA PROCESSING VALUE-ADDED INDUSTRY TO MATURE
- FRENCH, ESA, JAPANESE AND CANADIAN PROGRAMS PROVIDE DATA AMENABLE FOR POST-PROCESSING AT REASONABLE COST
- SPACE SEGMENT COSTS WILL BE REDUCED VIA THE SPACE STATION/SPACE PLATFORM
- DATA OBTAINED BY PRIVATELY FUNDED SENSOR CAN BE SOLD BY THE SENSOR OWNER WITHOUT GOVERNMENT RESTRICTIONS (OTHER THAN EQUAL PRICING POLICIES)
- U. S. GOVERNMENT WILL NOT COMPETE BY FLYING THEIR OWN SENSORS
- SENSOR LAUNCH, SERVICING, ETC WILL HAVE SAME PRIORITY AS OTHER CIVILIAN-GOVERNMENT PROGRAMS

## INSTRUMENTS NEEDED FOR IDENTIFIED COMMERCIAL MARKET (1990-2000)

Brief descriptions of instruments that will satisfy most of the commercial data requirements from 1990 to 2000 are given below. It is recognized that if the government continues research in satellite-born remote sensing instruments new capabilities will be uncovered that are not now foreseen and new uses will arise.

1. SAR in at least two frequencies (C and L bands) --- primarily geology, cartography, sea ice, and land use.
2. Multispectral Spectrometer, probably in several separate versions which contain the specialized spectral channels perceived to be of primary utility for the owners --- geology, forestry, agriculture, ocean color.
3. Wind-field scatterometer --- marine wind field for inclusion in global and regional forecasts of winds, waves.
4. Data collection platform --- to obtain in-situ meteorological data for inclusion in global and regional forecasts.

**INSTRUMENTS NEEDED FOR IDENTIFIED  
COMMERCIAL MARKET  
(1990 - 2000)**



**INSTRUMENT**

**APPLICATION**

- SYNTHETIC APERTURE RADAR (SAR)  
(C&L BANDS)
- MULTISPECTRAL (V&IR) SPECTROMETER
- WIND-FIELD SCATTEROMETER
- DATA COLLECTION PLATFORM

GEOLOGY, CARTOGRAPHY, SEA ICE

GEOLOGY, FORESTRY, AGRICULTURE,  
OCEAN COLOR

MARINE WIND AND WAVES

OBTAIN IN SITU METEOROLOGICAL DATA  
FOR INCLUSION IN FORECASTS

## REMOTE SENSING BUSINESS SCENARIOS

TRW has looked at three space business scenarios whereby a set of instruments are flown together to provide data to a set of users. Two dedicated free-flying remote sensing satellites and one set of instruments attached to a space station were considered. The free-flying satellites would be serviced by a polar orbiting space station or the STS. The space station attached instruments could be man-tended with reduced support cost.

## REMOTE SENSING BUSINESS SCENARIOS



1. FREE FLYING SATELLITE (WITH SAR AND MSS)
  - SERVICED BY SPACE STATION OR STS (BOTH WITH TMS)
  - COMMON INSTRUMENTS PROVIDE DATA FOR GEOLOGY, AGRICULTURE, AND LAND USE PLANNING
2. SEASAT FREE FLYING SATELLITE (WITH SAR, SCATTEROMETER, MSS, RADAR ALTIMETER, AND DCP)
  - SERVICED BY SPACE STATION OR STS (BOTH WITH TMS)
  - COMMON INSTRUMENTS PROVIDE DATA FOR OFF SHORE OIL OPERATIONS AND SHIPPING AND FISHING INDUSTRIES
3. POLAR ORBIT SPACE STATION ATTACHED INSTRUMENTS (MSS AND SAR)
  - SPECIFIED DATA OF PARTICULAR SITES PROVIDED ON CONTRACT
  - COMMON INSTRUMENTS PROVIDE DATA FOR GEOLOGY, CARTOGRAPHY, OFF-SHORE ACTIVITIES, EPISODIC EVENTS

REMOTE SENSING  
MISSION NO. 1  
EARTH SENSING SATELLITE

For this mission, the space station user buys and operates a spacecraft with a SAR and a V&IR imager, electronically tunable to satisfy geologic, agricultural, land use and hydrological requirements.

The major commercial data buyers are likely to be the grain traders and agricultural production groups because repetitive coverage is needed during the growing season.

Several government bodies could also be profitable customers.

REMOTE SENSING  
MISSION NO. 1  
EARTH SENSING SATELLITE



MISSION OBJECTIVES:

- PROVIDE PERIODIC DATA ON CROP CONDITIONS
- PROVIDE DATA ON PLANTED AREAS OF VARIOUS CROPS
- PROVIDE GEOLOGIC AND LAND USE DATA

INSTRUMENTS:

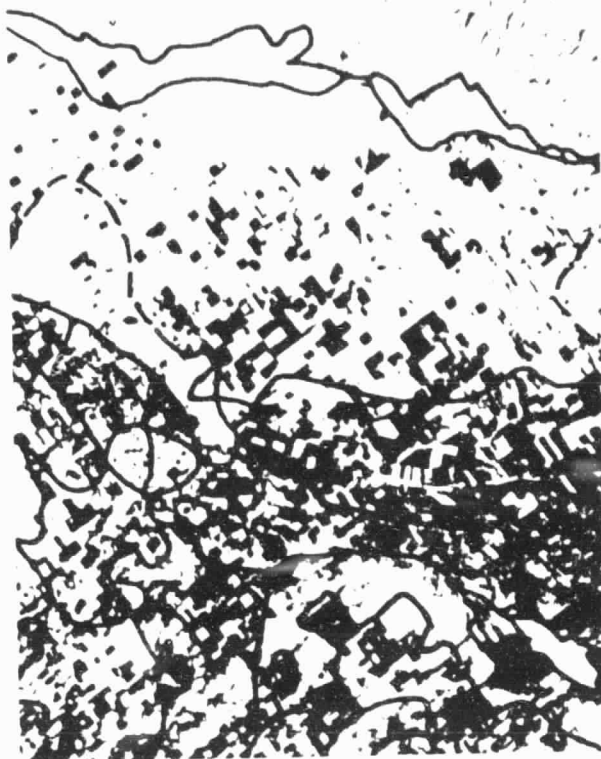
- V&IR IMAGER
- 2 FREQUENCY SAR
- STEREO CAPABILITY

USERS:

- AGRICULTURAL COOPERATIVES FARMS, USDA, GRAIN TRADERS
- OIL AND MINERAL EXPLORATION COMPANIES, DEPTS OF COMMERCE AND ENERGY, NATIONAL GEOLOGICAL SURVEY
- LAND DEVELOPMENT COMPANIES, GOVERNMENT LAND USE AGENCIES

SPACE STATION SCENARIO:

- POLAR ORBITING STATION RECEIVES, SERVICES, AND REDEPLOYS THE SUN SYNCHRONOUS SATELLITE



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ANTICIPATED PAYOFFS:

- REDUCED COST OF SPACE SEGMENT ENABLING ITS COMMERCIAL FUNDING
- REDUCED COST OF PRIMARY DATA
- IMPROVED U.S. BALANCE OF TRADE

## REMOTE SENSING MISSION #2 OCEAN SENSING SATFLLITE

For mission number 2, the space station user buys and operates a Seasat type of spacecraft using a Synthetic Aperature Radar (SAR), a scatterometer, V&IR imager adapted to a larger field of view and with less resolution accepted, a radar altimeter, and a Data Collection Platform (DCP) receiver.

There are two products. Data from the scatterometer, DCP, altimeter and SAR (not images) relate to sea state and weather. These data are used in weather models and must be provided frequently.

The imaging systems map ice, as an aid to shipping, and chart the oceans bio-productivity. These data are in increasing use by the U.S. fishing industry.

The U.S. government (NOAA) is the largest single user of civilian weather data. Should the space segments of all civilian weather services pass to a contractor, it is difficult to assess what value added services the NWS would perform, and so what they would buy in primary data. Even today, however, there are numerous profit making, civil organizations that perform special weather forecasting and communication services. Ten such companies were identified in a spot check of the membership of the National Ocean Industries Association. They typically are medium sized, doing a few hundred million dollars of business per year.

Those in the U.S. fishing industry who have used the phytoplankton and ocean temperature mapping (by JPL) from Seasat and Nimbus-7 have stated that continued use of these products would greatly improve the U.S. fishing industry. One source said that it would "double the take."

Without comprehensive consideration of all markets, the commercial operation of a Seasat type satellite seems marginal. Commercial feasibility of this class of satellite will probably depend on the magnitude of data sales to the U.S. government or to foreign governments and foreign commercial interests.

REMOTE SENSING  
MISSION NO. 2  
OCEAN SENSING SATELLITE



MISSION OBJECTIVES:

- PROVIDE DATA CONCERNING WEATHER AND SEA STATE WORLD-WIDE
- PROVIDE SEA ICE IMAGING AND MOVEMENT FORECASTS
- REDUCE COST AND TIME TO LOCATE FISH, INCREASE YIELD

INSTRUMENTS:

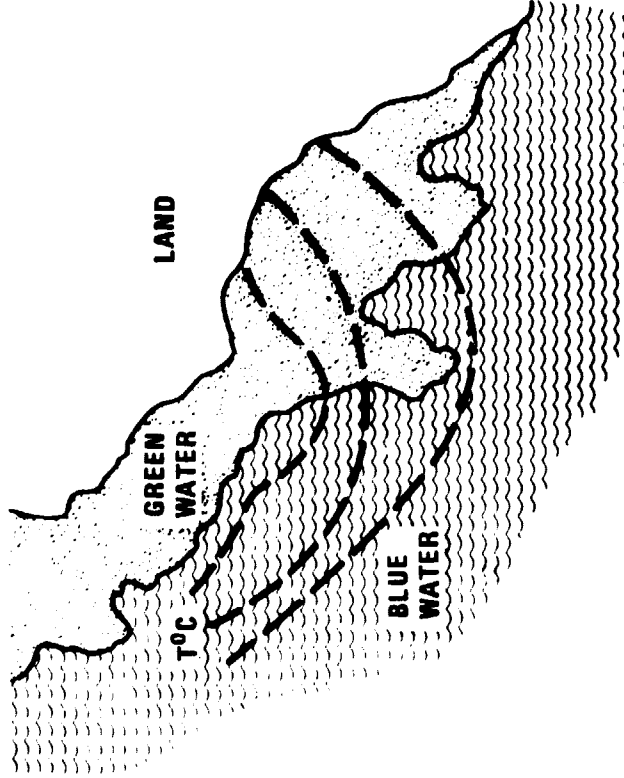
- SAR
- V&IR IMAGER
- SCATTEROMETER
- RADAR ALTIMETER
- DATA COLLECTION PLATFORM RECEIVER

USERS:

- OFF SHORE OIL OPERATIONS
- SHIPPING INDUSTRY
- FISHING INDUSTRY
- COMMERCIAL AND GOVERNMENT WEATHER PREDICTION ORGANIZATIONS

SPACE STATION SCENARIO:

- POLAR ORBITING STATION RECEIVES, SERVICES, AND REDEPLOYS THE HIGH ALTITUDE SATELLITE



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ANTICIPATED PAYOFFS:

- REDUCED COST OF SPACE SEGMENT ALLOWING ITS COMMERCIAL FUNDING
- REDUCED COST AND EXPANDED USE OF THE DATA
- IMPROVED U.S. BALANCE OF TRADE

# REMOTE SENSING MISSION #3 CONTRACT DATA ACQUISITION

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For this mission the space station user buys and operates specific instruments attached to the polar orbiting space station. He would provide specified data, of particular sites, on contract. The instruments would be V&IR imager, tuned to the specified bands, and SAR.

In a survey of the industrial geological community, the Geosat Committee found that "a user's interest is usually defined first by geographical area of interest and second by his/her specific application. Another important criterion is always 'How long must I wait to receive the data?' This factor may rank as high as 'What is the sensor?'" Geosat further said "Under current Landsat operational planning, NOAA will for the first time provide customers a system of ordering special acquisitions of data for the desired time and place on earth, thus allowing users with specific requirements to obtain from the Landsat coverage over their particular areas of interest at special cost." The system proposed here provides just this specialization. Further, if direct data dump to customers can be established as an operational mode, the data exclusivity together with selected and supervised data take to assure data quality will support an order of magnitude increase in price per scene from present practice. At this higher price per scene, this method of operation could become quite profitable.

REMOTE SENSING  
MISSION NO. 3  
CONTRACT DATA ACQUISITION



OBJECTIVE:

- PROVIDE SPECIFIED R.S. DATA AT PARTICULAR TIMES AND PLACES

INSTRUMENTS:

- V&IR IMAGER TUNABLE CHANNEL FREQ
- SAR, TWO FREQUENCY
- BOTH POINTABLE

USERS:

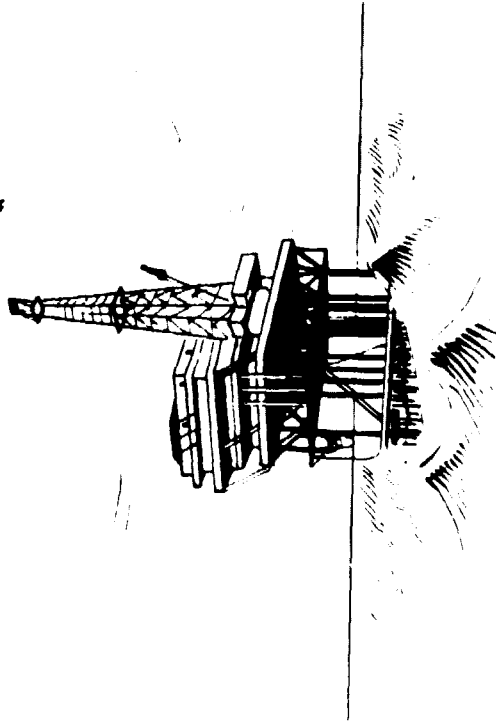
- OIL AND MINERAL EXPLORATION
- LAND USE AGENCIES
- GEOLOGICAL STUDY AGENCIES
- OFF-SHORE ACTIVITIES
- CIVIL EMERGENCY ACTIVITIES

SPACE STATION SCENARIO:

- INSTRUMENTS ON THE POLAR ORBITING SPACE STATION ARE POINTED AND OPERATED ON REQUEST
- DATA RELAYED DIRECTLY TO CUSTOMER IF REQUESTED

ANTICIPATED PAYOFFS:

- LOW COST AND SHORT LEAD-TIME FOR DATA MAKES SPECIAL ORDERS ATTRACTIVE



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## MISSION NO. 1 COST COMPARISON

The analysis is made to develop an understanding of the nature of savings possible through use of a polar orbit space station to launch and maintain a satellite in sun synchronous orbit. Two cases are developed. In the first, the commercial spacecraft carrying the instruments is launched by the STS. The instruments and leased bus are developed to full space standards for a five year life of independent operation. In the second, the instruments are brought to the space station by the STS, mated to the leased bus, taken by TMS to orbit, and maintained as necessary for five years. The design and development of the instruments is geared to the ready availability of space station maintenance. In this case, the D and D and manufacturing costs are reduced (about 20%) in accord with the many studies that have been made on possible cost savings when on-orbit maintenance is feasible.

Differences in launch cost are attributable to the difference in load factor on the shuttle as noted in the chart.

Use of a leased spacecraft bus is assumed in both cases. The price is TRW derived.

It is assumed that the space station tended spacecraft will require servicing once in its five year life, on the average.

It is to be noted that the savings for space station tending amounts to about 11% of the total costs.

# MISSION NO. 1 COST COMPARISON



	<u>STS LAUNCHED</u>		<u>SPACE STATION TENDED</u>	
	<u>TOTAL</u>	<u>PER YR. (1)</u>	<u>TOTAL</u>	<u>PER YR. (1)</u>
INSTRUMENTS				
STS LAUNCH (4)	\$90.0M (2) \$4.3M (1100 LBS)		\$76.0M (3) \$3.4M (1100 LBS)	
	<u>\$94.3M</u>	\$26.9M	<u>\$79.4M</u>	\$22.6M
LEASE BUS		\$ 7.0M		\$ 7.0M
SERVICING (ONLY @ \$3M)				\$ 0.6M
OPERATIONS		\$ 1.3M		\$ 1.0M
		<u>\$35.2M</u>		<u>\$31.2M</u>

Δ = \$4.0M

SAVINGS = 11%

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NOTES: (1) EQUIPMENT COSTS AMORTIZED OVER 5 YEARS WITH 10% PROFIT INCLUDED.

(2) A. LOOMIS, JPL

(3) 20% REDUCTION

(4) LAUNCH COSTS ASSUME 82% LOAD FACTOR FOR S.S. SERVICE

## SCENARIO FOR SELLING MISSION NO. 1 DATA

If the mission number 1 space station user prices his product at  $\$0.10/\text{km}^2$  with a scene of  $34000\text{km}^2$  ( $185 \times 185$ ) each scene computer compatible tape (CCT) with 7 to 9 channels sells for \$3400 ,NOAA 1984 TM=\$2800) with 10% of the customers wanting SAR data his sales average \$3740 per scene. This amounts to 8000 to 10000 scenes that he must sell year year. Possible customers are:

### Agriculture

Grain traders make their profits by using information. Presently, they depend heavily on rainfall data to estimate crop yields. Space imagery gives a more direct measure. They are interested in about  $10^7\text{km}^2$  (300 scenes) three times per year, sold to seven of the 12 major trading, banking, or brokerage companies would yield sales of 6300 scenes per year.

Major agri-business organizations such as Farmland Inc., Cotton Inc. service agricultural, rangeland and forestry groups having gross revenues > \$70 billion. These together with large cooperatives and large independent farms and timber companies constitute another market. Their farm areas in the U.S. extend to about 260 scenes (without SAR). Taken 5 to 9 times during the growing season they represent a potential sale of 1300 to 2000 scenes.

### Oil and Minerals

Oil exploration is the predominant potential customer. Exploration data for this industry costs about \$4 billion per year (mostly for seismic surveys) of this a 10% saving is possible with effective use of remote sensing products. Assume that 10% of this saving is paid for remote sensing services. Value added companies presently price their product at ~ 10 times the cost of original data. If this ratio continues there would remain about \$4M per year sales for the space segment operator (about 1200 scenes/year).

Without considering land use planning, or water resource management, it can be seen that a market for data exists, with revenue to the space segment operator that could match his costs and provide some profit.

## SCENARIO FOR SELLING MISSION NO. 1 DATA

### PRODUCT (DATA) PRICE

- ASSUME 10¢/KM<sup>2</sup>
- SCENE IS 185KM × 185KM = 34,225 KM<sup>2</sup>
- \$/SCENE = 3423

### REQUIRED SALES TO COVER ANNUALIZED EXPENSES: ≈ 9K TO 10K SCENES

(WORLDWIDE THERE ARE ABOUT 100K SCENES OF LAND EXCLUDING ARTIC AREAS AND SIBERIA)  
10K SCENES × \$3.423/SCENE = \$34.23M COMPARED TO \$31.2M COST

### REVENUE PROSPECTS

#### SCENES/YEAR

- GRAIN TRADERS	- 6300	} TO THIS ADD GOVERNMENT USERS OF LAND USE PLANNING AND WATER RESOURCE MANAGEMENT
- AGRIBUSINESS	- 1300 TO 2000	
- OIL EXPLORATION	- 1200	
	8,800 TO 9,500	

CONCLUSION: MISSION 1 LOOKS LIKE A VIABLE BUSINESS POTENTIAL

## SATELLITE REMOTE SENSING SPACE STATION BENEFITS

In a similar manner to the previous analysis, benefits for using space station tending have been developed for mission number 2. Mission number 3, by its nature, cannot be operated from the STS.

It can be seen that mission number 2 benefits are essentially the same as those for mission number 1. For later analyses it is assumed that these benefits are 11%, like Mission 1.



## SATELLITE REMOTE SENSING SPACE STATION BENEFITS

- BENEFITS OF USING SPACE STATION ARISE FROM:
  - REDUCED COST OF INSTRUMENTS DUE TO AVAILABILITY OF MAINTENANCE
  - REDUCED LAUNCH COST DUE TO HIGHER STS LOAD FACTORS
- APPROXIMATE COSTS FOR MISSIONS ARE:

	STS ONLY \$M	S.S. TENDED \$M	S.S. SAVINGS \$M	COST REDUCTION
MISSION #1	35.2	31.2	4.0	11%
MISSION #2	25.5	22.5	3.0	12%
MISSION #3	N.A.	22.1	—	

- THUS ASSUMED BENEFIT FROM USE OF SPACE STATION IS ABOUT 11%

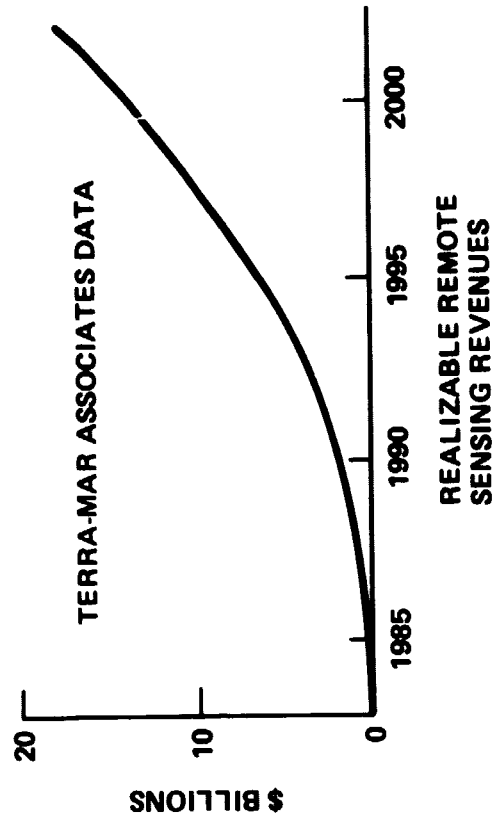
## REMOTE SENSING ECONOMIC ANALYSIS

Using revenues projected to be available to the space segment and the 11% cost savings for use of the space station, the savings by year are shown with the total of \$566 million possible cumulative savings in five years.

## REMOTE SENSING ECONOMIC ANALYSIS



	SPACE SEGMENT REVENUES \$M	SAVINGS THROUGH S.S. \$M (11%)
1995	—	—
1996	730	80
1997	880	97
1998	1030	113
1999	1180	130
2000	1330	146
<b>TOTAL 1995 — 2000</b>	<b>5150</b>	<b>566</b>



TOTAL REALIZABLE DATA REVENUES, 1995 — 2000 = \$51.5 BILLION

SPACE SEGMENT REVENUES (10%) = \$5.15 BILLION

SAVINGS OF SPACE STATION VS. STS TENDING (11%) = \$566 MILLION  
FOR 5 YEARS

\*WE ARE USING REVENUE AS AN ESTIMATE OF SPACE SEGMENT EXPENDITURES FOR THE STS



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## **Commercial Materials Processing in Space**

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#### MSP WORKSHOP PARTICIPANTS

A Materials Processing in Space Workshop was held at TRW in October, 1982. The participants are listed in the chart. Among them were most of the individuals in the United States who understand the promise of MPS and who are also senior technical individuals associated with commercial firms that process materials.

**Program Management**

**Division**

TRW Space &  
Technology Group



**MPS WORKSHOP PARTICIPANTS**

<u>PARTICIPANT</u>	<u>COMPANY</u>	<u>MPS RELATIONSHIP</u>
DR. J. BENJAMIN	INCO	TEA, ELECTROPLATING
MR. J. GRAHAM	DEERE AND COMPANY	TEA, METALS, CAST IRON
DR. E. G. YOUNG	DUPONT	TEA, CATALYSTS
MR. T. PIWONKA	TRW-AIRCRAFT COMPONENTS GROUP	IGI, METAL CASTING
COL. R. RANDOLPH	MICROGRAVITY RESEARCH ASSOC.	JEA, CRYSTAL PRODUCTION
MR. L. VAN DEN BERG	EG&G, INC.	P. I., VAPOR CRYSTAL GROWTH
MR. K. BRAGG	PARKER HANNIFIN CORP.	GENERAL INTEREST
MR. P. CHASE	BECKMAN INSTRUMENTS, INC.	GENERAL INTEREST
MR. N. KESSLER	A. E. STALEY MFG. CO.	ENZYME PRODUCTION
MR. S. R. NIXON	MPS CONSULTANTS	CONTRACTED SURVEY
DR. W. RALL	U.S. STEEL	METALS
MR. R. ROACH	MPS CONSULTANT	CHEMICAL PRODUCTION
MR. W. RYAN	BECKMAN INSTRUMENTS, INC.	GENERAL INTEREST
DR. R. F. SHAW	SHAW ASSOCIATES, INC.	CHEMICAL RESEARCH
DR. J. UNDERWOOD	NORTHROP R&TC	SEMICONDUCTORS
MR. D. YOEL	UTAH STATE UNIVERSITY	EQUIPMENT DEVELOPMENT

## MPS SPACE STATION WORKSHOP RESULTS

The workshop participants were asked to discuss their motivations for being interested in MPS. They were asked to state their opinions on the major needs for enabling commercial MPS and further to delineate the salient features of Space Station requirements for MPS.

The more frequently stated replies are listed on the chart.

## MPS SPACE STATION WORKSHOP RESULTS



### MOTIVATIONS

- INDUSTRY R&D MOTIVATED LARGELY BY MARKET PULL RATHER THAN TECHNOLOGY PUSH
- INITIAL INTEREST IS LOW-G MATERIALS SCIENCE STUDIES
- TO GO FARTHER COMMERCIAL MARKET ASSURANCE (PRODUCT FOR SALE) IS A MUST

### NEEDS

- 50 TO 100 RESEARCH SAMPLES INVOLVING 4 TO 8 FLIGHTS (GROUND ANALYSIS BETWEEN FLIGHTS) ARE REQUIRED TO UNDERSTAND A MATERIAL
- MUST REDUCE IMPLEMENTATION TIME (NEED 1 YEAR TO DATE FROM GO-AHEAD)
- NEED ASSURANCE FROM GOVERNMENT THAT PROGRAMS SUPPORTING EFFORT WILL CONTINUE
- ONLY PRODUCTION OF MATERIALS PROJECTED NOW ARE BY MDAC/JJ AND MRA

### SPACE STATION FEATURES

- A GENERAL PURPOSE MPS RESEARCH LAB CAN BE DEFINED – PARAMETERS WERE OFFERED
- MAN-IN-THE-LOOP EXPERIMENTS ON A SPACE STATION WILL BE USEFUL FOR RESEARCH
- PRODUCTION WILL BE PERFORMED ON A FREE FLYER OR SPACE PLATFORM

#### MPS SPACE STATION WORKSHOP RESULTS

At the end of the workshop, the results of previous discussions were explored in a general meeting. Out of this a number of statements were developed that could be agreed to by the majority of the participants. These are listed in the next two charts.

## MPS SPACE STATION WORKSHOP RESULTS



### MAJORITY STATEMENTS:

1. A SPACE STATION IS REQUIRED TO EXTEND AND COMPLETE INDUSTRY INTERESTS IN R&D
2. AN EVOLUTIONARY APPROACH TO SPACE STATION IS DESIRABLE -- MORE R&D IS NEEDED
3. BOTH A NATIONAL LABORATORY ON THE SPACE STATION AND FREE-FLYING PLATFORMS WILL BE NEEDED
4. QUANTIFYING COMMERCIAL PRODUCTION NEEDS IS HIGHLY SPECULATIVE AT THIS TIME. FIVE YEARS OF ADDITIONAL INDUSTRIAL RESEARCH IS NEEDED
5. GENERIC MPS RESEARCH MISSIONS CAN BE SPECIFIED. COMMODITY NEEDS (POWER, COOLING, EXPERIMENT NUMBERS) ARE LARGE AND CAN BE PROJECTED NOW



**MAJORITY STATEMENTS:**

6. INDUSTRY DOES NOT BELIEVE THAT NASA UNDERSTANDS THEIR NEEDS
  - MPS RESEARCH PROGRAM REQUIREMENTS ARE DEVELOPED BY ACADEMIC COMMUNITY — NOT INDUSTRY
  - SUGGEST ESTABLISHING A COMMERCIAL MPS USER COUNCIL OR CONSORTIUM TO ADVISE NASA
7. COSTS TO PARTICIPATE MUST BE REASONABLE, AND PROJECT LEAD TIMES SHORTENED (12-14 MONTHS) FOR SIGNIFICANT COMMERCIAL ACTIVITY TO OCCUR
8. INDUSTRY IS RELUCTANT TO INVEST LARGE AMOUNT NOW
  - HIGH RISK PROGRAMS WITH BOTH HIGH CAPITAL REQUIREMENTS AND LOW PROFITABILITY OF SUCCESS ARE NOT OFTEN SUPPORTED
  - MORE THAN SINGLE YEAR PROGRAM COMMITMENT IS NEEDED
  - MORE GUARANTEES BY GOVERNMENT ARE NEEDED (E.G., GUARANTEED EXISTENCE OF CAPABILITY)

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## INDUSTRIAL MATERIALS RESEARCH

### MANNED LABORATORY

A predominant issue raised by the workshop participants is the need for more extensive, commercially oriented, low gravity research. To reduce costs an industrial laboratory as part of the Space Station was thought of as an important step. In addition to helping hold down costs, this concept was appealing because it allows a great deal more flexibility in planning a research project and in its execution. It is more like the present working relationship with a company laboratory than is Shuttle/Spacelab activity. The Space Station laboratory also allows longer duration experiments than are reasonable with Spacelab.

## INDUSTRIAL MATERIALS RESEARCH MANNED LABORATORY



### MISSION OBJECTIVES:

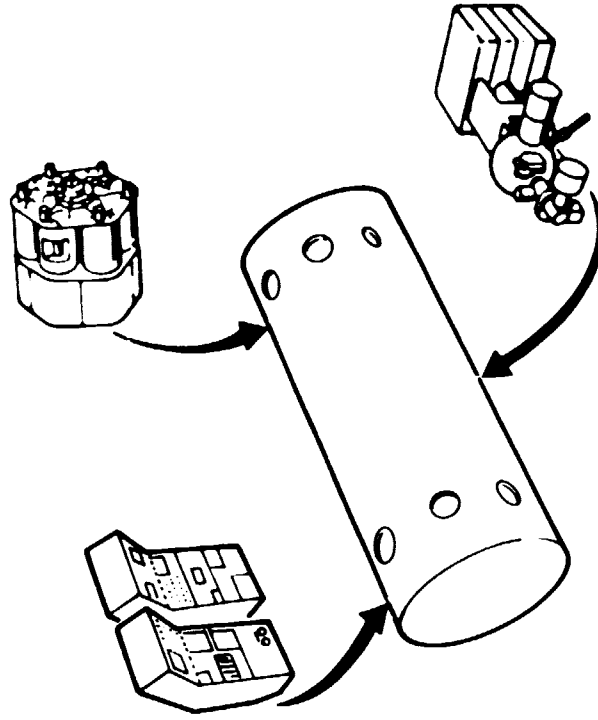
- LOW COST SPACE RESEARCH IN COMMERCIAL MATERIALS/PROCESSES
- QUALITY CONTROL TESTING OF MATERIALS PRODUCTION

### USERS:

- PROCESSORS OF MATERIALS FOR COMMERCE

### SPACE STATION SCENARIO:

- PERMANENTLY ATTACHED LABORATORY
- GENERAL PURPOSE INSTRUMENTS PROVIDED BY INDUSTRIAL CONSORTIUM
- PROCESSORS PROVIDED BY INVESTIGATORS
- INITIAL LAB MULTIPURPOSE; LATER, SEPARATE FLUIDS AND METALS LABS



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### ANTICIPATED PAYOFFS:

- COST AND FLEXIBILITY OF RESEARCH COMMENSURATE WITH COMMERCIAL R/D
- ALLOWS FAMILIAR MANNED EXPERIMENTATION WITH FLEXIBILITY IN AUTOMATION
- SAVINGS IN OPERATIONS AND TRANSPORTATION THROUGH IN PROCESS QUALITY CONTROL
- LONGER MISSION DURATIONS THAN WITH STS

GENERAL PURPOSE MATERIALS PROCESSING  
RESEARCH FACILITY

Equipments that were named as essential to the industrial research laboratory are listed with their approximate masses and sizes. The sizes are expressed in terms of the amount of standard 19" rack space that would be used. This is the most likely accommodation method that would be used. Some items would need to be rearranged to fit this format rather than the bench/desk top format used on earth.

The equipment listed will fit easily into a Spacelab long module.

# GENERAL PURPOSE MATERIALS PROCESSING RESEARCH FACILITY \*



GENERAL PURPOSE EQUIPMENT	MASS (KG)	SPACE #19" RACK	GENERAL PURPOSE EQUIPMENT	MASS (KG)	SPACE #19" RACK
<b>METALS LAB.</b>					
WORK BENCH		1	GENERAL		
CUTOFF SAW	10		LABORATORY COMPUTER	200	1/2
POLISHER	20		SPARE PARTS (10%) AND TOOLS	70	1/2
METALURGICAL MICROSCOPE	5		SUPPLIES	100	1/2
MICROHARDNESS TESTER	16			1086	7
SCANNING ELECTRON MICROSCOPE	500	2	RESEARCH EQUIPMENT		
X-RAY ATTACHMENT EVAPORATOR			RESEARCH FURNACES		
ELECTRICAL AND MAGNETIC PROPERTIES TESTERS	20	1/2	INVESTIGATOR PROVIDED (4)	1500	2
			ELECTROPHORESIS AND OTHER FLUID SYSTEMS		
			INVESTIGATOR PROVIDED (4)	500	2
				2000	4
<b>FLUIDS LAB</b>					
TLC CHROMATOGRAPHIC SYSTEM ATTACHMENTS	45	1/2			
SPECTROPHOTOMETER ATTACHMENTS	70	1			
SELECTED MEASUREMENT EQUIPMENT	30	1/2			

\*BASED ON WORKSHOP RESULTS/COMMENTS

## AUTOMATED MATERIALS PROCESSING FACILITY

Most commercial production of materials in space will require fairly long periods in a very low gravity condition (on the order of 10's of days). Additionally, commercially reasonable quantities will require fairly large amounts of nearly continuous power (5 to 10 kw depending on the materials and processes). For these reasons, the space materials factories are usually thought of as entities each operating on its individual free flying resource module. The factories should be in orbits that allow regular servicing by the Space Station at intervals on the order of 3 months.

Factories such as this one could also provide research processing where long periods of low gravity ( $< 10^{-5}g$ ) are required.

## AUTOMATED MATERIALS PROCESSING FACILITY



### MISSION OBJECTIVES:

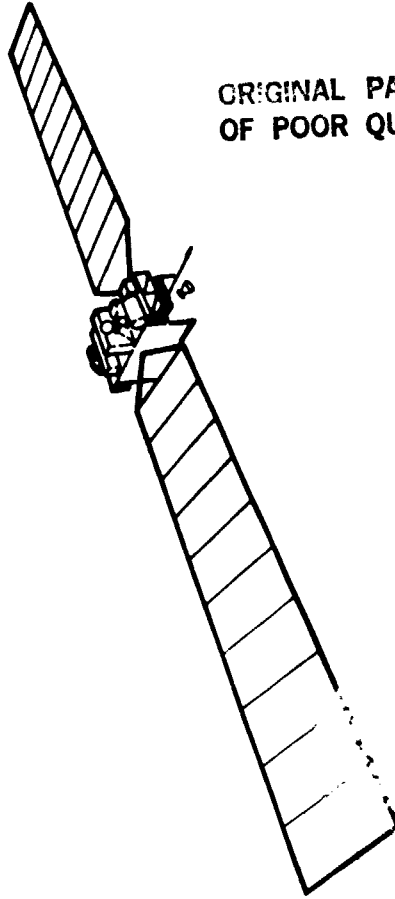
- PRODUCTION OF A COMMERCIALY SIGNIFICANT MATERIAL

### USERS:

- IN-SPACE PRODUCERS OF MATERIALS FOR COMMERCE

### SPACE STATION SCENARIO:

- CARRIER PLATFORM PROVIDES POWER, COOLING AND LONG TERM LOW GRAVITY ENVIRONMENT
- SPACE STATION RETRIEVES PLATFORM REMOVES PROCESSED MATERIALS, SERVICES PLATFORM AND PAYLOAD, WAREHOUSES MATERIALS BETWEEN SHUTTLE VISITS



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### ANTICIPATED PAYOFFS:

- PRODUCTION OF UNIQUE, HIGH VALUE MATERIALS FOR PROFITABLE SALE ON EARTH

## ASSUMPTIONS FOR MATERIALS PROCESSING IN SPACE

These assumptions are made in order to postulate scenarios for the development of commercial MPS and so to assess the benefits of the Space Station to MPS operations.

## ASSUMPTIONS FOR MATERIALS PROCESSING IN SPACE



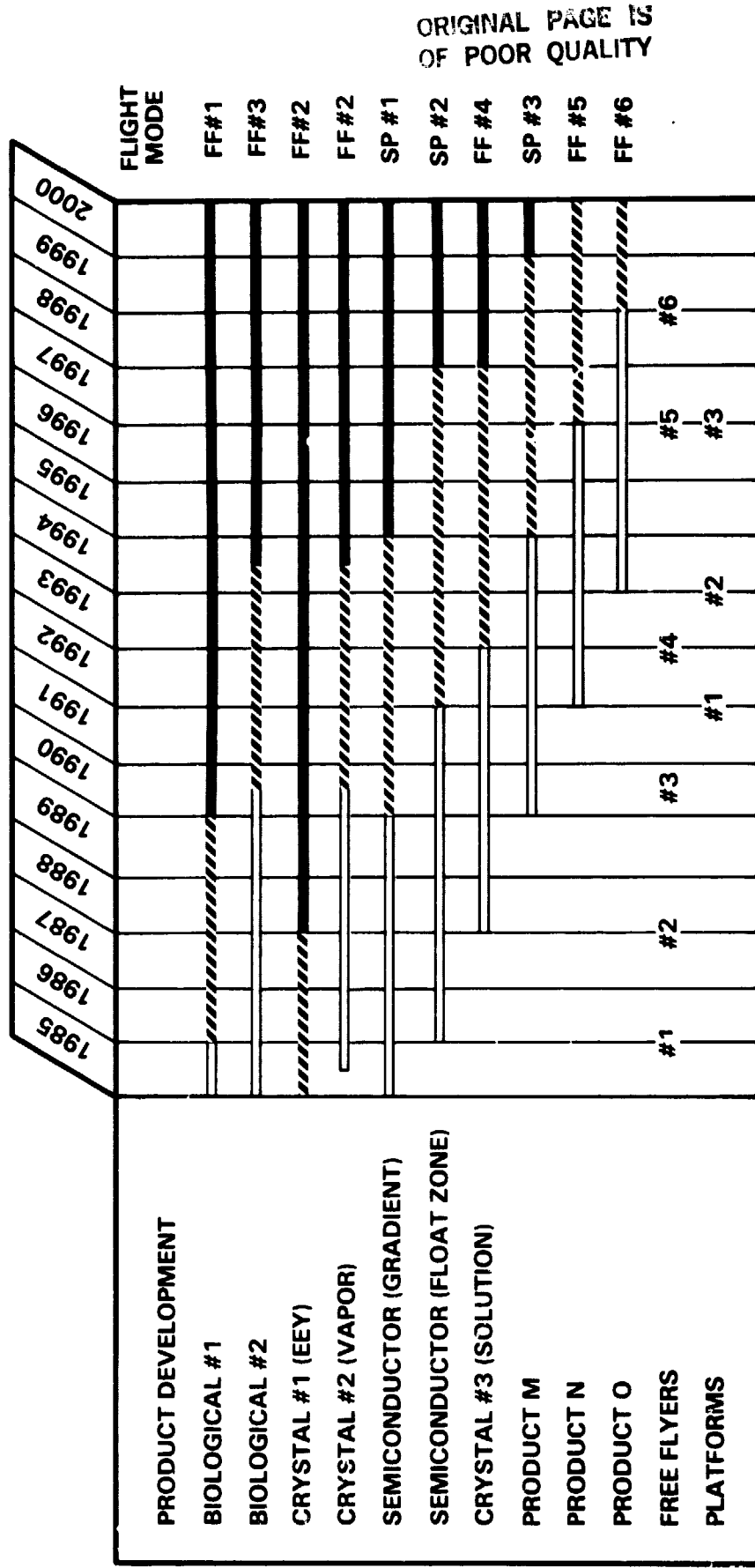
- THE McDONNELL DOUGLAS JEA WILL RESULT IN A PRODUCTION PRODUCT
- ANOTHER BIOLOGICAL PRODUCT JEA WILL START RESEARCH IN 1984 AND RESULT IN PRODUCTION
- THE MICROGRAVITY RESEARCH ASSOCIATES EFFORT WILL RESULT IN A JEA AND IN A PRODUCTION PRODUCT
- ANOTHER CRYSTAL GROWTH PRODUCT (LIKELY A DETECTOR MATERIAL) WILL BECOME A JEA AND START RESEARCH IN 1985
- OTHER PRODUCTS WILL GO INTO PRODUCTION LATER AT A RATE OF ABOUT ONE PER TWO YEARS
- NEW PRODUCT REQUIRES 5 YEARS OF RESEARCH ON THE STS. THE SPACE STATION CAN REDUCE THIS TIME TO 2 YEARS
- 5 YEARS OF PILOT PRODUCTION AND MARKETING ACTIVITIES IS REQUIRED PRIOR TO FULL SCALE PRODUCTION
- FINAL PREPRODUCTION ACTIVITIES WILL BE PERFORMED IN THE PRODUCTION FACILITY WHICH WILL LIKELY BE A FREE FLYER

## COMMERCIAL MATERIALS PRODUCTION

### STS SCENARIO

It should be noted that each product goes through a development process that includes about five years of research to understand the processing of a type of material and explore the boundaries of the materials' characteristics. When a material is considered sufficiently promising it will be taken into the pilot production stage. This involves enlarging the production facilities to produce large quantities so that scale up effects can be understood and to produce large enough quantities for testing by prospective users of the material. Except for one instance, each factory flies on its individual free flight resource module.

# COMMERCIAL MATERIALS PRODUCTION STS SCENARIO



R&D  
 PILOT PRODUCTION & MARKETING  
 PRODUCTION

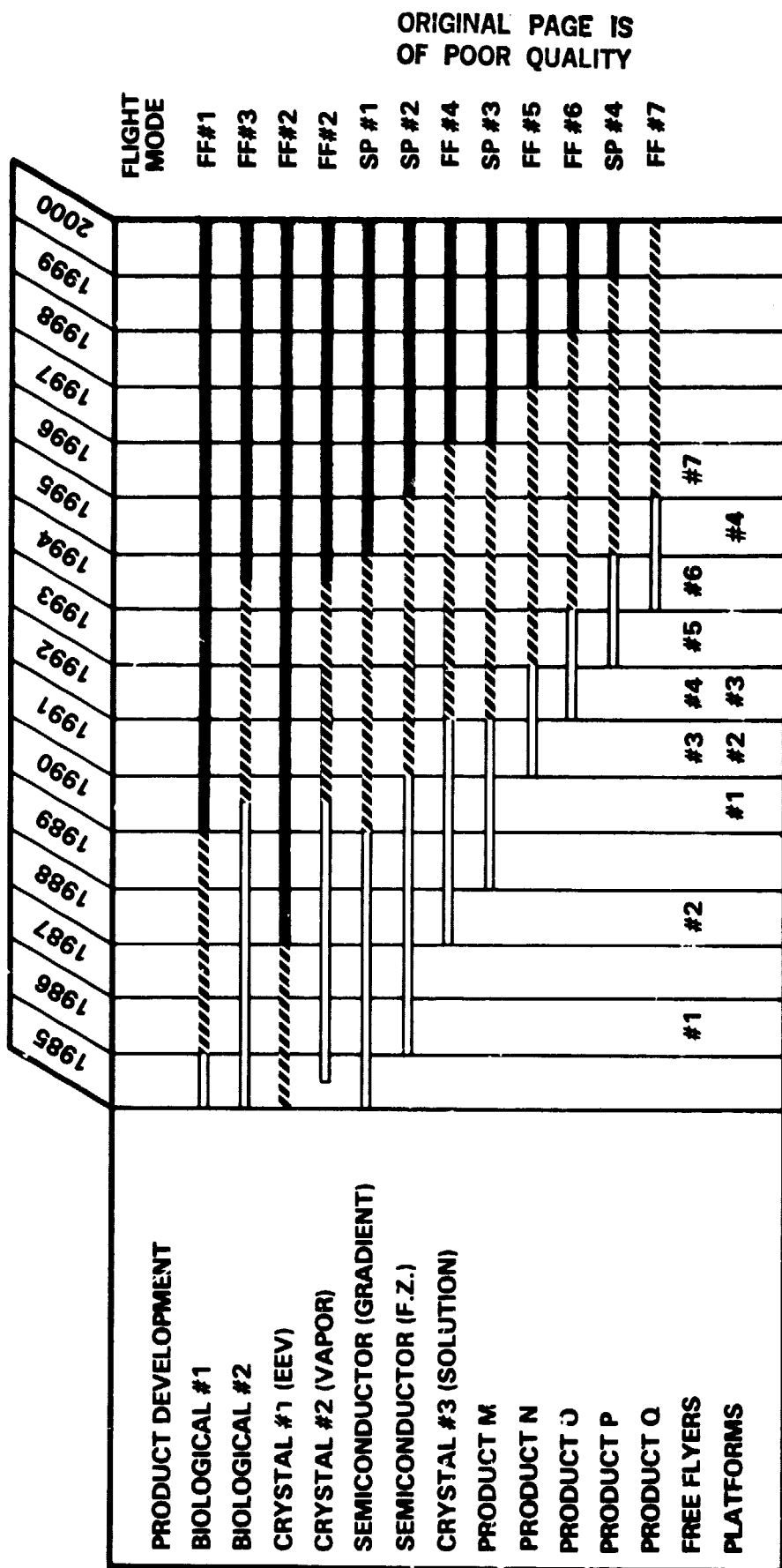
## COMMERCIAL MATERIALS PRODUCTION

### SPACE STATION SCENARIO

This scenario uses the same assumptions as the STS scenario except that it is assumed that adequate research can be performed to identify and characterize a product in two years rather than 5 years. Pilot production, in both cases, will likely be performed on a free flying facility and so the five year period for this activity is not expected to shorten with use of the Space Station.

It can be seen that more products enter the production phase, in the period between 1990 and 2000, with this scenario.

# COMMERCIAL MATERIALS PRODUCTION SPACE STATION SCENARIO



==== R&D  
 ///// PILOT PRODUCTION & MARKETING  
 ■■■■■ PRODUCTION

## MATERIALS PROCESSING IN SPACE

### SPACE STATION BENEFITS

A Space Station can benefit commercial materials production in several ways: Research is facilitated and its costs can be reduced so that production may be started earlier and more products are likely to be discovered. During production the Space Station eases the harvesting and provides more support access to the factory. It can also reduce costs through the higher average Shuttle load factor possible with the Space Station.

Based on the previous scenarios, and assuming production quantities of 100 kg per year for small factories (on free fliers) and 600 kg/yr for large factories (on space platforms), the table shows comparative yearly production quantities. In this example the nearly double production in the year 2000 is attributable solely to shortened research and facilitated introduction of new products.

# MATERIALS PROCESSING IN SPACE SPACE STATION BENEFITS



• MPS SPACE STATION BENEFITS ARISE FROM THREE SOURCES:

- RESEARCH CONDUCTED ON SPACE STATION RATHER THAN STS (NO NEED TO RELAUNCH FACILITY)
- SHORTENED RESEARCH PERIOD AND THUS ENABLES MOVE TO PRODUCTION EARLIER
- IMPROVED LOAD FACTOR ON THE SHUTTLE  $\approx$  25% FOR MATERIAL AND FACILITY TRANSFER

• COMPARATIVE PRODUCTION QUANTITIES COULD BE:

QUANTITY PRODUCED EACH YEAR (KG)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
STS	200	200	200	200	200	1000	1000	1000	1700	1700	1700	9100
SPACE STATION	200	200	200	200	400	1000	1600	2300	2400	2500	3100	14100

- AS PRODUCTION INCREASES THE SPACE STATION WILL SERVICE THE MPS PRODUCTION FACILITIES ALLEVIATING THE STS SERVICING REQUIREMENTS (36 STS SERVICES REQUIRED IN 2000 WITHOUT SPACE STATION)

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## **LEO Satellite Assembly, Test and Servicing**

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## BENEFITS OF ON-ORBIT SPACECRAFT ASSEMBLY AND TEST

This chart and the next list some of the benefits perceived for doing some assembly and test of spacecraft on-orbit at a Space Station.

Spacecraft/satellites designed for on-orbit assembly and servicing are different than current space vehicles. New design concepts have been developed to take advantage of the cost savings available from on-orbit assembly and servicing. Current structural and equipment mounting approaches are modified to an approach placing the equipment in structurally distinct, easily accessible modules. The modules must be easily accessible by on-orbit operations such as EVA. The electrical interface across separation points is minimized by, for example, using data buses. More automation of module functions and control will be necessary. The design of the satellite and the modules are interrelated. However, the constraints are primarily geometric and can be made not to intrude on the functional performance of the satellite.

## **BENEFITS OF ON-ORBIT SPACECRAFT ASSEMBLY AND TEST**



- PROVIDES FOR MORE EFFICIENT LOADING OF SHUTTLE BY TRANSPORTING THE SPACECRAFT MODULES AND APPENDAGES IN PACKING CASE CARRIERS RATHER THAN ASSEMBLED IN THE OPERATIONAL CONFIGURATION.
- DEPLOYMENT OF APPENDAGES BY MANNED OPERATIONS REDUCES THE NUMBER OF ACTUATORS; ASSURES COMPLETE DEPLOYMENT; INCREASES SAFETY BY ELIMINATING ORDNANCE.
- ENABLES ON-ORBIT FUELING REDUCING LIFT OFF WEIGHT AND INCREASING STS SAFETY.
- ALLOWS SPACECRAFT TO BE OF LARGER DIAMETER, GREATER LENGTH AND/OR GREATER WEIGHT THAN THE STS CARGO BAY HANDLES IN A SINGLE LOAD.
- REDUCES STS TRANSPORTATION COSTS VIA LIGHTER MORE COMPACT STRUCTURE.

BENEFITS OF ON-ORBIT SPACECRAFT ASSEMBLY AND TEST (CONT'D)

See comments on facing page for the preceding chart.

## **BENEFITS OF ON-ORBIT SPACECRAFT ASSEMBLY AND TEST (CON'T)**

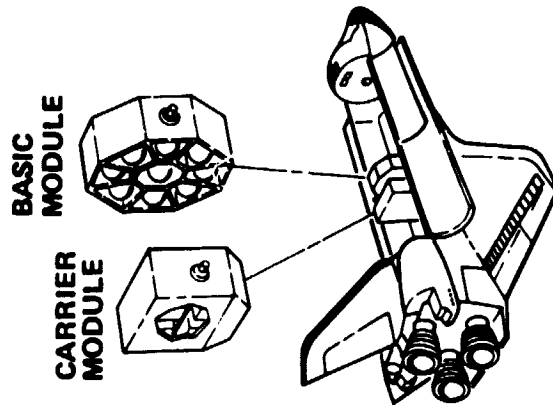


- DESIGN AND TEST OF MODULES FOR STS ENVIRONMENT IS NOT REQUIRED.  
(MODULES PROTECTED BY THE SPECIAL CARRIER)
- REUSABLE CARRIER MODULE SATISFIES BOTH INITIAL DELIVERY AND  
LOGISTICS SUPPORT REQUIREMENTS
- THERMAL SUBSYSTEM CAN BE TRIMMED ON-ORBIT, REQUIRING LESS  
GROUND TEST
- SPARES CAN BE CARRIED ON THE INITIAL LAUNCH, FOR IMMEDIATE USE IF  
REQUIRED, OR STORED ON THE SPACE STATION FOR LATER USE

## SPACECRAFT DESIGN FOR ASSEMBLY AND TEST ON-ORBIT

This chart shows one configuration compatible with concepts for assembly and test on-orbit. The basic module can be diameter equal to the Orbiter bay diameter. Its structure can be light weight. The subsystem modules, arrays, etc., are packaged in a special carrier module. Assembly of the modules onto the basic structure is done on-orbit.

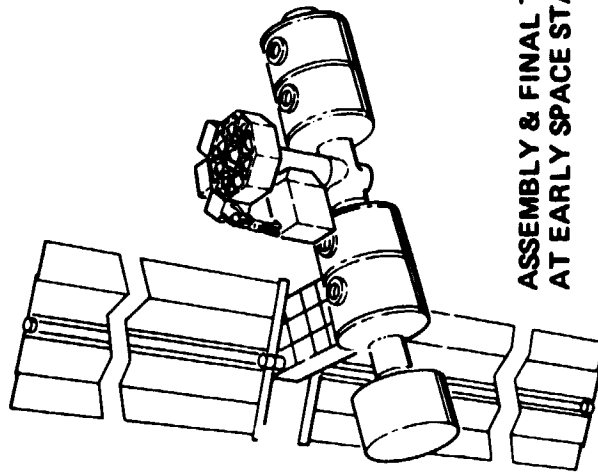
# SPACECRAFT DESIGN FOR ASSEMBLY & TEST ON-ORBIT



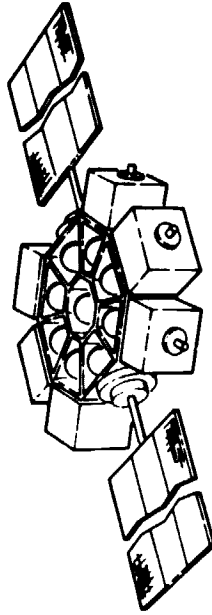
BASIC  
MODULE

CARRIER  
MODULE

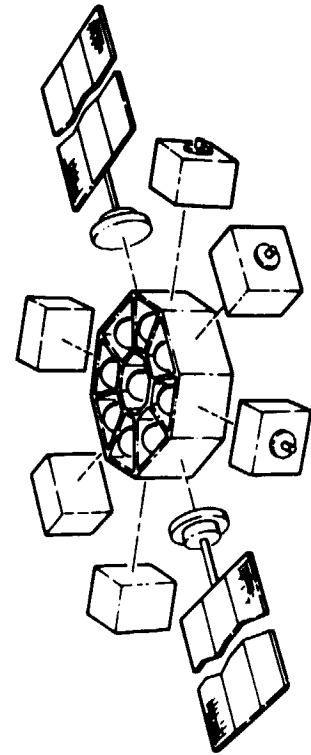
PACKED, PARTIALLY  
ASSEMBLED IN ORBITER



ASSEMBLY & FINAL TEST  
AT EARLY SPACE STATION



FREE FLYERS/PLATFORMS



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#### SUMMARY - POTENTIAL SAVINGS (BENEFITS) WITH SOME ASSEMBLY & TEST ON-ORBIT

This chart lists the potential savings for each scenario where savings are felt to exist. Four types of savings are listed -- and all four are related to the idea of assembly and test on-orbit. The cost savings shown are derived on subsequent charts.

# SUMMARY - POTENTIAL SAVINGS (BENEFITS) WITH SOME ASSEMBLY AND TEST ON-ORBIT



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	SAVINGS (BENEFIT) - \$ (M)		
	SCENARIO #2	SCENARIO #3	SCENARIOS 4 OR 5
ASSEMBLY AND TEST ON-ORBIT - USING LARGE ORUs AND CONVEN- TIONAL COMPONENT PACKAGING	490	385	504
STS TRANSPORTATION COST SAVINGS	51	40	52
VALUE ATTRIBUTED TO SPARES CARRIED TO ORBIT AND USED IN INITIAL CHECKOUT	179	141	185
VALUE ATTRIBUTED TO CHANGES IN COMPONENT PACKAGING	221	174	228
TOTAL	941	740	969

NOTE: ASSEMBLY AND TEST ON-ORBIT USING STS ONLY (SCENARIOS 0 & 1) IS ASSUMED  
NOT VIABLE. BENEFIT EXISTS ONLY WITH SPACE STATION (SCENARIOS 2, 3, 4, 5).

## GROUND RULES AND ASSUMPTIONS

This chart summarizes the key groundrules used in deriving the benefits of on-orbit assembly and test.

## GROUND RULES AND ASSUMPTIONS

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- SPACE STATION STUDY MISSION MODEL USED AS BASIS FOR ASSESSING BENEFIT.
- ANALYSIS IS FOR SPACECRAFT BUS ONLY i.e., DOES NOT INCLUDE PAYLOADS – SP ATTACHED/PALLETS, MATERIALS PROCESSING PLATFORMS AND SS ATTACHED "PAYLOADS" ARE TREATED AS SPACECRAFT. ADDING PAYLOADS TO ASSESSMENT WOULD ADD MORE BENEFIT.
- SPACE STATION SERVICES AND TRANSPORTATION OF PROPELLANTS ARE NOT CHARGED.
- ASSEMBLY AND TEST ON-ORBIT IS BASICALLY NOT VIABLE USING SHUTTLE ONLY BECAUSE TIME ON-ORBIT IS NOT AVAILABLE. (SCENARIOS 0 & 1)

## SPACE STATION ON-ORBIT AI&T IMPACT

This chart shows the breakdown of estimates for each of three spacecraft configurations with three different assembly and test approaches: 1) conventional assembly and test, 2) modular ground assembly and test and 3) on-orbit assembly and test. The "conventional" approach is a box-by-box buildup on the structure in a typical high bay. It is the baseline. The other two configurations are modular, probably by subsystem. The "ground A&T" is not designed for on-orbit servicing. The benefit of its modularization is in the production flow. The initial design and first unit costs are higher than the conventional approach. The spacecraft designed for on-orbit servicing has the same functional division for its modules, but the modules are large orbital replacement units (ORUs) which can be installed or replaced on-orbit. All three approaches use conventional component packaging. The analysis shows an approach availing itself of on-orbit assembly and test has both lower development (DD&TE) costs and lower production costs. (It must be remembered, however, that Space Station charges are not included in these estimates -- only preparation for on-orbit assembly and test is included.)



# SPACE STATION ON-ORBIT A1&T IMPACT

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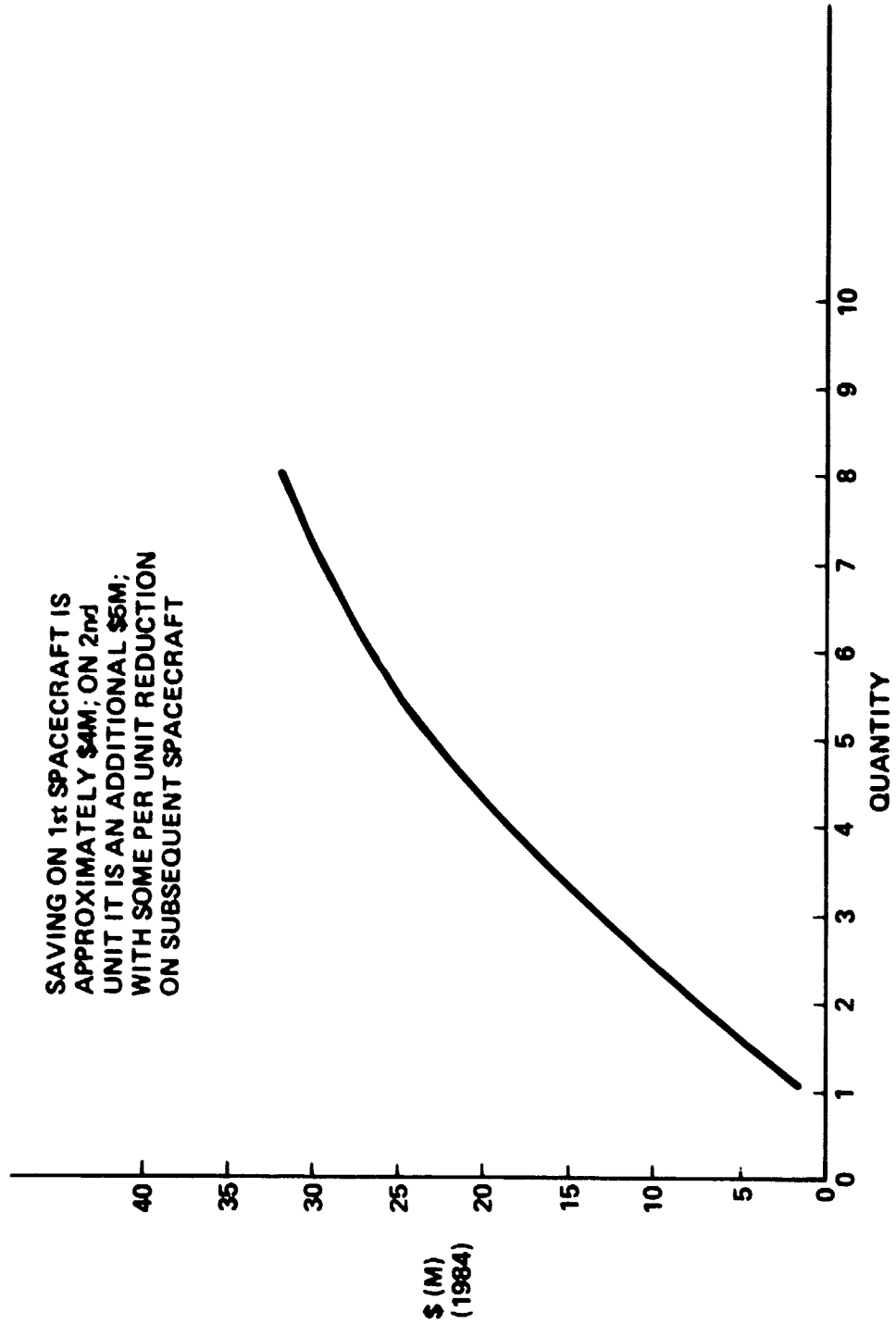
DESCRIPTION	CONVENTIONAL			MODULAR		ON-ORBIT	
	Z OF HWHR\$	DOTBE \$(M)	ASSY & TEST HWHR\$	GND ASSY & TEST DOTBE \$(M)	ASSY & TEST DOTBE \$(M)	ASSY & TEST DOTBE \$(M)	ASSY & TEST DOTBE \$(M)
SATELLITE HARDWARE COST		65.00	30.00				
SYSTEM ENG	0.18	11.70	0.03	11.70	0.99	11.70	0.99
SUBSYSTEM							
ATTITUDE CONTROL							
POWER	0.24	15.60	0.17	15.60	5.10	15.60	4.80
PROPULSION	0.19	12.35	0.31	12.35	10.23	12.35	9.71
STRUCTURE	0.07	4.55	0.15	4.55	4.95	4.55	3.60
MECHANISMS	0.24	15.60	0.19	17.16	6.27	14.04	4.56
TTBC	0.12	1.10	0.07	7.80	2.10	2.34	0.63
THERMAL	0.10	6.50	0.08	6.50	2.40	6.50	2.30
CREW SYSTEMS	0.05	3.25	0.03	3.25	0.90	3.58	0.90
INTERFACCE DESIGN		0.00		0.00	0.00	2.00	0.00
TO STS	0.02	1.30	0.00	1.30	0.00	1.80	0.00
TO SS	0.03	0.00	0.00	0.00	0.00	1.80	0.00
ASSEMBLY & TEST (GROUND)							
SYSTEM TEST							
SUBSYSTEM							
ATTITUDE CONTROL							
POWER			2.00		1.00		1.00
PROPULSION			0.77		0.69		0.69
STRUCTURE			1.40		1.38		1.38
MECHANISMS			0.68		0.67		0.49
TTBC			0.94		1.03		0.62
THERMAL			0.32		0.32		0.04
CREW SYSTEMS			0.36		0.32		0.32
NR A1&T			0.14		0.14		0.14
SYSTEM TEST			0.00		0.00		0.10
DYNAMIC							
THERMAL VACUUM							
LAUNCH OPS							
GROUND SUPPORT EQUIP							
SUBSYSTEM TEST EQUIP							
ELEC. GND SUPPT EQUIP							
MECH GND SUPPT EQUIP							
FLIGHT SUPPORT EQUIP (FSE)							
MODULE CARRIER							
CREW TRAINING							
TOTALS							
TYPE TOTAL							
DELTA							

#### SAVINGS WITH ON-ORBIT A&T VERSUS QUANTITY OF A GIVEN TYPE

This chart shows the savings as a function of quantity. The first unit savings (including DDT&E) from the preceding chart is \$4M. The savings on the second was taken as equal to the savings on the first production units (\$5M), making a total of \$9M for a quantity of two. Successive quantities show a somewhat smaller per unit savings assuming a learning curve identical for both approaches and therefore a smaller delta. Again, the on-orbit A&T approach has all space station services rendered "free" for this assessment.



## SAVINGS WITH ON-ORBIT A&T VERSUS QUANTITY OF A GIVEN TYPE



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## LAUNCHES BY CATEGORY PER YEAR - 28.5° MISSION MODEL

This chart summarizes the 28.5° LEO mission model for this analysis of A&T on-orbit. It shows a total of 314 spacecraft which could derive some benefit from on-orbit assembly and test. Note that SP attached and SS attached payloads are treated as "spacecraft" to give them some value in the assessment; however, each unique payload is counted only once, i.e., relaunches are not counted. This chart is an example. Similar charts were made for polar orbit (PEO).

Note: The Commercial Mission Model is a subset of this model. Obviously, transfer/planetary are science missions. The transfer/earth are primarily commercial communication satellites although DoD is also included.



# LAUNCHES BY CATEGORY PER YEAR 28.5° MISSION MODEL

CATEGORY	YEAR											TOTAL	# TYPES
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000		
CO-ORBIT FREE FLYER	—	1	2	3	—	2	1	—	1	1	—	11	7
TRANSFER/EARTH ORBIT	—	32	27	30	27	23	31	28	28	28	24	275	35
TRANSFER/PLANETARY	1	—	2	2	2	1	1	1	—	—	—	10	10
SP ATTACHED	1	2	1	—	—	—	—	—	—	1	—	5	2
MATERIALS PLATFORMS	1	—	—	—	2	1	—	—	1	1	—	6	3
SS ATTACHED	3	2	—	—	1	1	—	—	—	—	—	7	3
TOTAL	6	37	32	35	32	28	33	29	30	27	25	314	60

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- THIS ADAPTATION OF MISSION MODEL USED FOR SCENARIO #3 BENEFIT ASSESSMENT (WITHOUT POLAR ORBIT VEHICLES)
- SIMILAR ADAPTATION MADE FOR POLAR ORBIT TO ADD TO THIS MODEL FOR SCENARIOS 2, 4, 5.

## SAVINGS WITH A&T ON-ORBIT - CONVENTIONAL COMPONENTS

This chart estimates for scenario 3 the savings for A&T on orbit using conventional components. The total vehicles in each category are listed from the preceding chart and the number of different types is guessed. (This guess allows pulling a number off of the quantity/savings curve.) When totalled, the potential savings is \$1,285M. This is a somewhat optimistic amount since it assumes that all spacecraft are designed modularly for on-orbit A&T and that an equal benefit per spacecraft type results. It also makes the assumption that the space station is capable; i.e., manned for such a workload. For a more conservative approach, it is assumed 1/2 of the users implement the A&T on-orbit operation and derive the estimated benefit.

For scenarios 2, 4, and 5, the savings was increased by the multipliers noted in the chart. This multiplier accounts for the additional spacecraft in polar orbit.

# SAVINGS WITH A&T ON-ORBIT CONVENTIONAL COMPONENTS SCENARIO NO. 3



(ALL ENTRIES IN MILLIONS OF 1984 DOLLARS)

CATEGORY	(1) TOTAL VEHICLES	(2) NO. TYPES	(3) NO. OF VEHICLES PER TYPE	(4) SAVING PER TYPE (\$ M)	(5) TOTAL SAVINGS (2) x (4) (\$ M)
CO-ORBIT	11	7	1.6	5	35
TRANSFER-EARTH ORBIT	275	35	7.9	33	1155
TRANSFER-PLANETARY	10	10	1.0	2	20
SP ATTACHED	5	2	2.5	11	22
MATERIALS PLATFORMS	6	3	2	8	24
SS ATTACHED	7	3	2.3	10	30
TOTAL					1285 M

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OF POOR QUALITY

- ASSUMING 30% OF THE POTENTIAL USERS OF ON-ORBIT A&T ACTUALLY IMPLEMENT IT AND DERIVE THE ESTIMATED SAVINGS, THE BENEFIT BECOMES \$385.5 M
- THIS ASSESSMENT IS FOR 28.5° LAUNCHES (SCENARIO 3). FOR SCENARIO 2, \$385.5M WAS INCREASED UPWARD BY 1.27 TO ACCOUNT FOR POLAR. FOR SCENARIOS 4 OR 5, \$385.5M WAS INCREASED BY 1.31 TO ACCOUNT FOR POLAR.

#### SHUTTLE TRANSPORTATION COST SAVINGS WITH A&T ON-ORBIT

Weight savings result from carrying spacecraft to orbit without propellant, partially assembled and with modules protected from the STS environment by special packaging. Weight savings are primarily due to lightened structure in the basic structure, the propulsion subsystem and components. The reduced weight translates to reduced shuttle transportation costs as shown in the chart. The weight of the module carrier (at 200 lbs.) is an increase yielding a net weight reduction estimated at 350 lbs.

## SHUTTLE TRANSPORTATION COST SAVING WITH A&T ON-ORBIT



<u>SUBSYSTEM</u>	<u>WEIGHT CHANGE</u>
PROPULSION	(-) 200 LBS
STRUCTURE (AVERAGE TOTAL 800 LB)	(-) 200 LBS
(3) COMPONENTS (AVERAGE TOTAL 1500 LB)	(-) 150 LBS
CARRIER	(+) 200 LBS
	(-) 350 LBS

WITH SHUTTLE TRANSPORTATION COST AT \$1,100/LB AND ASSUMING 1/3 OF THE 314 LAUNCHES IN THE MISSION MODEL ARE REDUCED IN WEIGHT AS SHOWN, THE TRANSPORTATION COST SAVING FOR SCENARIO 3 IS \$40 M.

- NOTES: (1) ESTIMATE BASED ON WEIGHT ONLY. SAVINGS IN LENGTH MAY ALSO BE A FACTOR.
- (2) PROPELLANT AVAILABLE ON ORBIT WITHOUT TRANSPORTATION CHARGE.
- (3) NEW, LIGHTWEIGHT DESIGN
- (4) ASSESSMENT FOR SCENARIO #2 WAS INCREASED BY 1.27 TO ACCOUNT FOR PEO; SIMILARLY SCENARIOS 4 & 5 WERE EACH INCREASED BY 1.31.

## VALUE ATTRIBUTED TO SPARES CARRIED TO ORBIT AND USED IN INITIAL CHECKOUT

This benefit is based on the assumption that using the space station as a way station during initial on-orbit operations (including assembly and test) will 1) catch some initial failures and 2) allow repair of those failures using spares carried to orbit and stored in the space station. Again, as in previous charts, the methodology is shown for scenario 3. The resulting saving for scenario 3 is factored up for scenarios 2, 4, and 5 to add the benefit from spacecraft at polar orbit (PEO). The basic assumption is that about 5% of the total number of satellites and satellite equivalents in the mission model will experience failures which can be detected during checkouts at the space station and that 20% of these (1% of the total of 314 in the model) can be repaired at the space station. The value of this 1% calculated as shown in the chart is the benefit.

## VALUE ATTRIBUTED TO SPARES CARRIED TO ORBIT AND USED IN INITIAL CHECKOUT

- THIS ASSESSMENT ASSUMES 20% OF INITIAL SPACECRAFT FAILURES (REPRESENTING 1% OF TOTAL SPACECRAFT) ARE UNIQUELY SERVICEABLE BY THE SPACE STATION
- ESTIMATE OF VALUE (SCENARIO #3)

1) ASSUMED VALUE PER SPACECRAFT	\$80 M
2) TOTAL NUMBER OF "SPACECRAFT" IN MISSION MODEL	314
3) VALUE OF 1% OF 314	\$251.2 M
4) COST ASSUMED FOR STS TRANSPORT OF SPARES (100,000 LBS AT \$1,100/LB)	\$110 M
5) POTENTIAL SAVING	\$141.2 M
- ESTIMATE OF VALUE – SCENARIO #2  
SCENARIO #3 SAVING X 1.27
- ESTIMATE OF VALUE – SCENARIO #4 OR #5  
SCENARIO #3 SAVING X 1.31

#### SAVINGS WITH NEW COMPONENT PACKAGING APPROACH

This savings estimate is again detailed for scenario 3 with other scenarios ratioed from scenario 3 to account for satellites at polar inclination (PE0) deriving benefit. The premise of this savings (benefit) estimate is that component design can be less expensive (approaching aircraft component costs) if components are protected from the shuttle environment. This protection is made possible because the concept of assembly and test on-orbit allows components to be transported to orbit in special "packing cases" or carriers which protect from the shuttle environment.

## SAVINGS WITH NEW COMPONENT PACKAGING APPROACH



SUBSYSTEM	TYPICAL COST OF SUBSYSTEM (\$ M)	COST ATTRIBUTABLE TO ELEC. COMPONENTS	
		%	(\$ M)
<u>SPACECRAFT</u>			
ATTITUDE CONTROL	3.9	70	2.73
POWER	7.2	30	2.16
PROPULSION	3.3	10	.33
STRUCTURE	4.3	0	—
MECHANISMS	9.0	0	—
DATA HANDLING	2.1	100	2.10
THERMAL	.6	10	.06
			<u>7.38</u>

- FOR SCENARIO #3 SAVINGS WITH NEW PACKAGING APPROACH ESTIMATED AT 30% OF \$7.4 M = \$2.2 M. WITH ONE FOURTH (79) OF THE 314 NEW SPACECRAFT IN THE MISSION MODEL, POTENTIAL SAVINGS ARE \$2.2M x 79 = 174 M.
- SCENARIO #2 SAVINGS IS \$174 M X 1.27 = \$221 M; FOR SCENARIOS 4 OR 5 SAVING IS \$174 M x 1.31 = \$228 M.

EXAMPLE SPACECRAFT TYPES THAT MIGHT BENEFIT  
FROM ORBITAL SERVICING BEYOND 1990

There are several types of missions that benefit from servicing provided by the space station. This chart lists eight types of missions that are potential beneficiaries of on-orbit servicing provided by a space station at LEO 28.5° and/or polar inclinations.

## EXAMPLE SPACECRAFT TYPES THAT MIGHT BENEFIT FROM ORBITAL SERVICING BEYOND 1990



1. LARGE OBSERVATORY TYPE
  - SPACE TELESCOPE
  - AXAF
  - COSMIC RAY OBSERVATORY
2. ENVIRONMENTAL MONITORING SATELLITES
  - LONG DURATION EXPOSURE FACILITY
  - SOLAR CYCLES AND DYNAMIC MISSIONS
  - EARTH RADIATION BUDGET SATELLITES
3. OPERATIONAL EARTH RESOURCES SATELLITES
  - OPERATIONAL LANDSAT OBSERVE SYSTEM
  - EARTH SURVEY SYSTEMS
  - PRIVATELY OWNED EARTH RESOURCES SATS
4. UNMANNED SPACE PLATFORMS
  - SASP
  - 25 kW POWER SYSTEM
5. SPECIAL MISSION SATELLITES
  - GAMMA RAY OBSERVATORY
  - UPPER ATMOSPHERIC RESEARCH SATELLITE
  - OCEAN RESEARCH SATELLITES
  - HEAVY NUCLEI EXPLORER
6. COMMERCIAL SATELLITES
  - COMMUNICATION SATELLITES
  - MATERIALS PROCESSING SATELLITES
  - EARTH RESOURCES MAPPING SATELLITES
7. EXPERIMENTAL SORTIE ACTIVITIES
  - SPACE LAB
  - SPACE TEST PROGRAM
8. DoD SATELLITES
  - GLOBAL POSITIONING SATELLITE
  - DEFENSE METEOROLOGICAL SATELLITE
  - COMMUNICATION SATELLITES
  - SPACE SURVEILLANCE SYSTEMS
  - CLASSIFIED SYSTEMS

SPACECRAFT MANUFACTURERS AND  
SATELLITE OPERATORS CONTACTED

To obtain data for the TRW/NASA Space Station Needs, Attributes and Architectural Options study for tasks pertaining to the use and value of servicing operations, we contacted the USA and European companies shown on this chart. The data and comments we received were categorized into information on:

1. Value given to on-orbit service operations in areas such as components testing, alignment of control devices, assembly of large elements, environmental/dynamic response testing, propellant loading, subsystem/payload changeout, etc.
2. Time frame when on-orbit service operations will be required.
3. Benefits of any orbital servicing operations.
4. Cost reduction suggestions for orbital servicing operations.
5. Servicing operations methods visualized (IVA, EVA, RMS, or combinations).
6. Number and location of satellites requiring servicing by the Space Station.
7. Use of TMSs and OTVs for servicing functions.

## SPACECRAFT MANUFACTURERS AND SATELLITE OPERATORS CONTACTED



### USA

BALL AEROSPACE

FAIRCHILD

FORD AEROSPACE

GENERAL ELECTRIC

HUGHES

RCA

TRW

### EUROPEAN

AERITALIA

AEROSPATIALE

BRITISH AEROSPACE

ERNO

MATRA

MBB

SAAB-SCANIA

## LEO SATELLITE SERVICING NEEDS

The responding spacecraft manufacturers (nine of fourteen) listed on the preceding chart show the maximum benefit of on-orbit service in the areas listed on this chart.



## LEO SATELLITE SERVICING NEEDS

SPACECRAFT MANUFACTURERS SEE HIGHEST SPACE STATION LEO SATELLITE SERVICING USE IN SUPPORTING:

- ANALYSIS AND TROUBLESHOOTING PRIMARILY BY VISUAL OBSERVATION
- GROWTH
- REPLENISHING CONSUMABLES
- REPLACING COMPONENTS
- PROVIDING GROUND STATION-LIKE OPERATIONS
- CLEANING AND REFURBISHING SURFACES

#### SUMMARY - LEO AND PEO SERVICING BENEFIT

This summary chart is largely self-explanatory. Using the TRW-generated mission model, servicing benefits at both 28.5° LEO and polar inclinations were examined. Benefits are assumed for both contingency, i.e., unscheduled service and planned or scheduled service. A percentage - 10% - of spacecraft in LEO 28.5° and polar are assumed to benefit from contingency service and 100% of planned services are assumed beneficiary to services available from the Space Station. Materials processing platforms servicing and harvesting were not included in this assessment of benefits. Benefits of servicing at polar inclination is applicable to scenarios 2, 4 and 5 where there is a Space Station at polar orbit. Benefit of the polar Space Station is shown in this and subsequent charts to be \$291M each for scenarios 4 and 5. For scenario 2, the benefit (not shown in these charts) is estimated at \$191M.

## SUMMARY LEO AND PEO SERVICING BENEFIT

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- SERVICING OF SATELLITES AT LEO – BOTH 28.5° AND POLAR INCLINATIONS – WERE EXAMINED
- VALUE OF BOTH PLANNED AND CONTINGENCY SERVICING WAS ASSESSED
- TRW'S MISSION MODEL FOR 1990 THRU 2000 WAS THE BASIS FOR THE ANALYSIS
- IT WAS CONCLUDED THAT 28.5° LEO SERVICING PROVIDES A BENEFIT OF \$484M; POLAR ORBIT SERVICING ADDS UP TO \$291M (SCENARIO 4, 5)
- BENEFIT OF MATERIALS PROCESSING PLATFORM SERVICING WAS NOT INCLUDED IN THIS ASSESSMENT

## BENEFITS ANALYSIS APPROACH

Service models by year were constructed for 28.5° LEO and polar inclinations (PEO). The mission model was used for this derivation. A total number of service events was estimated for both LEO and PEO, and the number of service events was the basis from which benefits were derived (see next chart). Separate benefit estimates were made for each scenario type. Scenarios 0 and 1 were treated as identical for purpose of this benefit assessment. So were scenarios 4 and 5.



## **BENEFITS ANALYSIS APPROACH**

- **CONSTRUCTED SERVICE MODEL AT LEO AND PEO USING THE MISSION MODEL (MPS PLATFORMS EXCLUDED)**
- **ESTIMATED COST OF SERVICING MISSIONS WITH STS ONLY (SCENARIO 0), SPACE PLATFORMS ONLY (SCENARIO 1) AND WITH THE SPACE STATION (OTHER SCENARIOS).**
- **ESTIMATED VALUE OF SERVICE AS A PERCENT OF THE NOMINAL COST OF A REPLACEMENT SPACECRAFT NEEDED TO COMPLETE A MISSION WITHOUT THE SERVICING BENEFIT.**
- **DERIVED NET SAVING (BENEFIT) AND SPREAD BY YEAR USING THE LEO AND PEO SERVICE MODEL.**

## SUMMARY - LEO AND PEO SERVICE MODELS

Satellite and satellite equivalents are counted from the mission model. Free flyers are given a value of "1" each. Pallets attached to platforms and the Space Station are valued at less than "1" equivalent satellite since they are assumed a bit less complex than free flyers. The assumption (line 2 of the chart) that 10% of the satellite/satellite equivalent count will benefit from satellite servicing is arbitrary. Planned service events (line 3) are as directly counted from the mission model. Lines 5 and 6 divide the service events between applicable mission classes - science/applications and commercial. "Commercial" in this analysis is for commercial R&D only. As noted earlier, commercial missions are a subset of this model.



## SUMMARY - LEO AND PEO SERVICE MODEL

	28.5° LEO	POLAR
1) SATELLITE & SATELLITE EQUIVALENTS	62	14
2) ESTIMATE OF CONTINGENCY SERVICE OPERATIONS FOR SATELLITES OF (1) ABOVE (10%)	6	1.4
3) PLANNED SERVICE EVENTS (MP SERVICE EXCLUDED)	13	10
4) TOTAL SERVICE EVENTS	19	11.4
5) SERVICE EVENTS FOR SCIENCE AND APPLICATIONS	92%	100%
6) SERVICE EVENTS FOR COMMERCIAL	8%	—

## ESTIMATED COST OF SERVICING - LEO & PEO SATELLITES

The following comments are made about this chart:

- 1) The cost of an STS flight is \$70M for this assessment. This cost is perhaps low by 15% and it therefore makes the cost estimate low and the net saving a bit too high.
- 2) The \$80M does not include a payload. Savings from payload servicing would increase the benefit.
- 3) The amount of cargo space used is an obvious, significant driver of the STS only cost.
- 4) The "STS Only" cost is applicable to scenarios 0 and 1. "With SS" is applicable to the rest of the scenarios - scenarios 2, 3, 4 and 5.

# ESTIMATED COST OF SERVICING LEO AND PEO SATELLITES



## ● GROUND RULES

- SPACE STATION AVAILABLE COST FREE
- STS COST AT \$1.3 M/FT OF CARGO BAY
- THE AVERAGE SATELLITE OR EQUIVALENT HAS A VALUE OF \$80 M AND SPARES FOR SERVICING ARE ESTIMATED AT 10% OF \$80 M
- AN AVERAGE SERVICE MISSION USES 5 FT OF CARGO BAY AT A COST OF \$6.5 M WHEN THE SPACE STATION IS USED FOR SERVICING
- AN AVERAGE SERVICE MISSION COSTS ABOUT ONE HALF A SHUTTLE FLIGHT (\$35 M) WITH NO SPACE STATION

## ● ESTIMATE

STS COST  
SPARES COST  
FOR 19 SERVICE OPERATIONS  
FOR 11.4 SERVICE OPERATIONS

28.5°		POLAR	
STS ONLY	WITH SS	STS ONLY	WITH SS
\$ 35 M	\$ 6.5 M	\$ 35 M	\$ 6.5 M
8 M	8.0 M	8 M	8.0 M
\$ 43 M	\$ 14.5 M	\$ 43 M	\$ 14.5 M
\$817 M	\$275.5 M	—	—
—	—	\$490.2M	\$165.3 M

## ESTIMATED VALUE OF SERVICE - LEO AND PEO SATELLITES

The value of service is a function of service events where two constants are assumed:

- 1) each satellite or satellite equivalent has a value of \$80M and 2) 50% of \$80M is saved on the average by each service event.

Value of service =  $(0.5) (80M)$  (Number of Service Events)



## ESTIMATED VALUE OF SERVICE TO LEO AND PEO SATELLITES

- VALUE OF SERVICE AT 28.5° IS BASED ON A PERCENTAGE OF THE APPROXIMATED VALUE OF THE 19 SATELLITES OR SATELLITE EQUIVALENTS SERVICED

19 SATELLITES @ \$80 M EACH      \$1,520 M

ASSUME 50% OF MISSION IS  
SAVED BY SERVICING AND THAT  
SAVING DIRECTLY CORRELATES  
WITH SATELLITE VALUE.

THEN (0.5) (1,520) IS VALUE  
OF SERVICE      \$ 760 M

- SIMILARLY FOR 11.4 SATELLITES SERVICED AT POLAR:

11.4 SATELLITES @ 80 M EACH      \$ 912 M

ASSUME 50% OF MISSION IS  
SAVED BY SERVICING AND THAT  
SAVING DIRECTLY CORRELATES  
WITH SATELLITE VALUE.

THEN (0.5) (912) IS VALUE  
OF SERVICE      \$ 456 M

## BENEFIT OF SERVICING - LEO AND PEO SATELLITES

The data on this chart is applied as follows:

- |               |  |
|---------------|--|
| 1) Scenario 0 | No benefit or perhaps a negative benefit.  |
| 2) Scenario 1 | No benefit or perhaps a negative benefit.  |
| 3) Scenario 2 | 28.5° plus polar benefit equal to \$775M. This benefit is optimistic compared to scenarios 4 and 5 since scenario 2 has less capability than 4 or 5. |
| 4) Scenario 3 | 28.5° only for a benefit of \$484M. (There is no PEO Space Station in scenario 3).   |
| 5) Scenario 4 | 28.5° plus polar benefit equal to \$775M.  |
| 6) Scenario 5 | Same as scenario 4.  |



## BENEFIT OF SERVICING LEO AND PEO SATELLITES

- THE BENEFIT IS THE VALUE OF THE SERVICE MINUS THE COST

VALUE COST	28.5°		POLAR	
	STS ONLY	WITH SS	STS ONLY	WITH SS
	\$760 M <u>817 M</u> (\$ 57 M)	\$760 M <u>276 M</u> \$484 M	\$456 M <u>490 M</u> (\$ 34 M)	\$456 M <u>165 M</u> \$291 M

- THE AVERAGE BENEFIT OVER 11 YEARS (1990 THROUGH 2000 INCLUSIVE) IS \$44 M/YEAR FOR 28.5°
- THE AVERAGE BENEFIT OVER EIGHT YEARS (1993 THRU 2000 INCLUSIVE) IS \$36.4 M/YEAR FOR POLAR
- WITH STS ONLY NO BENEFIT SEEMS TO EXIST; THE KEY DRIVER IS THE PERCENT OF COST OF AN STS FLIGHT ALLOCATED TO THE SERVICE MISSION



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## Space Tourism

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## TRAVEL AND ENTERTAINMENT SURVEY

A discussion of the Space Station definition project together with a questionnaire of interest were sent to 87 executives in organizations such as hotels, airlines, travel agencies and various recreation enterprises.

Of the 16 that replied, seven expressed interest. TRW interviewed each of these by telephone. We found that they are casually interested and would be pleased to continue to receive information and to contribute further. Those interviewed said they believe that some people are willing to pay \$100K to \$200K to go into Space but lower (\$10K-\$30K) prices will be required to develop the market.

## TRAVEL AND ENTERTAINMENT SURVEY



- A DISCUSSION OF THE SPACE STATION DEFINITION PROJECT AND A QUESTIONNAIRE WERE SENT TO 87 EXECUTIVES IN THE TRAVEL AND ENTERTAINMENT INDUSTRIES
  - HOTELS
  - AIRLINES
  - TRAVEL AGENCIES
  - RECREATION ENTERPRISES
- RECEIVED 18 REPLIES  $\approx$  20%
- 8 EXPRESSED INTEREST
- INTERVIEWED THE 7 MOST INTERESTED: MAJOR STATEMENTS WERE
  - COST MUST BE LOW (\$10K - \$30K) PER PERSON FOR EXTENSIVE MARKET IN SPACE TRAVEL
  - ON AN INITIAL, LIMITED SEATING BASIS A MARKET EXISTS AT \$100K TO \$200K PER FLIGHT
  - MOST THINK THAT GOING TO A SPACE STATION IS A MUCH MORE ATTRACTIVE VENTURE THAN STS FLIGHT
- IN 1967 BARON HILTON COMMENTED (AT AN AAS ANNUAL MEETING IN DALLAS) THAT IF NASA COULD GET LAUNCH COSTS DOWN TO \$1C/LBS, HE WOULD BUILD A HOTEL IN SPACE

#### SPACE TOURISM USER RESPONDERS

The organizations that responded to our survey questionnaire are listed. The individuals are those who signed their companies' response and were interviewed by telephone. All of the individuals are of vice-president rank, most are in staff and planning positions.

## SPACE TOURISM USER RESPONDERS



### USERS RESPONDING

FIELD ENTERPRISES INC.  
NATIONAL CAR RENTAL SYSTEM INC.  
AM. SOCIETY FOR TRAVEL AGENTS  
AIR TRANSPORT ASSN.  
TAFT BROADCASTING INC  
UNITED AIRLINES  
COMMUNICATION INTERNATIONAL  
WESTERN HOTELS (2)  
EASTERN AIRLINES  
TRANS WORLD AIRLINES  
HYATT HOTELS CO.  
MCA  
AMERICAN AIRLINES INC.  
AMFAC HOTELS  
U.S. DEPT. OF COMMERCE (TRAVEL & TOURISM)

### INTERVIEWED

J. J. DORAN  
  
WILLIAM T. BAUMANN  
EDWARD A. BEAMISH  
  
HARVEY C. CANNOVA  
  
JESSIE M. LIEBMAN  
  
HAROLD M. HAAS  
  
KENNETH C. FREE

## TRAVEL AND ENTERTAINMENT BENEFITS ANALYSIS

It is expected that before 1990 people, other than astronauts and scientists, will have flown on the Shuttle. In the first stage, they will occupy spare seats, at NASA expense, to contribute to the public image. Later, it is expected that there will be some informal bidding for seats, leading to general auctions, then to straight sales of spare seats on short flights.

It is assumed that all flights to the space station will have spare seats except those that are used to change out the space station crew, every 90-days; and that there will not be an overt commercial move to provide more flight opportunities than this.

Our consultation with travel and hotel executives leads to two assumptions: (1) having a space station to go to will maintain a high level of interest commensurate with a per flight price at 100 to 200 thousand dollars and (2) a polar orbit flight will sustain a higher price than 28.5° orbit because they will pass over more of the earth's territory. We have priced polar flights at \$250K and LEO flights @ \$150K.

# TRAVEL AND ENTERTAINMENT BENEFITS ANALYSIS



- ASSUME 3 AVAILABLE SEATS ON ALL FLIGHTS EXCEPT SPACE STATION CREW CHANGE FLIGHTS
- FLIGHTS TO 28.5° STATION PRICED AT \$150K/PERSON TRIP
- FLIGHTS TO POLAR STATION PRICED AT \$250K/PERSON TRIP
- REVENUES COULD BE:

YEAR	AVAILABLE SEATS		REVENUES \$M
	INCLINATION		
	28.5°	90°	
1990	9		1.35
1991	9		1.35
1992	21		3.15
1993	21		3.15
1994	18		2.70
1995	33	12	7.95
1996	30	9	6.75
1997	30	6	6.00
1998	21	9	5.40
1999	24	6	5.10
2000	30	3	5.25
TOTAL	246	45	48.75

## OVERALL COMMERCIAL CONCLUSIONS

The overall conclusions regarding commercial benefits of a Space Station are shown on the facing page. Primary economic benefits result from lower transportation costs and servicing of GEO communication satellites.

## OVERALL COMMERCIAL CONCLUSIONS



- A LEO 28.5° SPACE STATION WILL SIGNIFICANTLY BENEFIT COMMUNICATIONS SATELLITES (UP TO \$1.5 B/YEAR)
  - LARGE SYSTEM TESTING AND ASSEMBLY
  - AROTV LAUNCHES AND GEO SERVICING
  - HIGHER STS LOAD FACTORS
- REMOTE SENSING FROM POLAR ORBIT IS A BLOSSOMING COMMERCIAL MARKET
- POLAR ORBIT REMOTE SENSING NEEDS CAN BE MET WITH THE STS AND PLATFORMS THROUGH 2000
- MATERIALS PROCESSING IN SPACE WILL BE ACCELERATED BY A SPACE STATION — HARD TO ESTIMATE COMMERCIAL MARKET
- OUR STUDY SHOWS THAT BY 2000, THE COMMERCIAL INDUSTRY WILL HAVE ACCUMULATED BENEFITS OF \$9.0 BILLION (1984 \$) VIA A 28.5° SPACE STATION (SCENARIO 3)